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AD INEXPLORATA

FLIGHT PLANNING AND CONDUCT OF THE X-24A LIFTING BODY FLIGHT TEST PROGRAM

JOHNNY G. ARMSTRONG
Aerospace Engineer

TECHNOLOGY DOCUMENT No. 71-10

AUGUST 1972

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FOREWORD

The X-24A, USAF S/N 66-13551, was air launched for 28 free flights between 17 April 1969 and 4 June 1971. This technology document presents the flight planning and conduct aspects of the X-24A lifting body flight test program, along with a brief discussion of significant test results. References 1 through 8 are related documents that have been or will be published.

The author wishes to acknowledge the efforts of Captain Walter D. Seward in providing simulation support that was mandatory for X-24A flight planning and pilot training. Acknowledgement is also made to those individuals who, through close working relationships, crossed organizational ties to successfully accomplish a research flight test program of this type - the Joint NASA/USAF Test Team.

The participation of AFFTC personnel in this program was authorized by AFFTC Project Directive 69-38, and was performed under Program Structure 680A.

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Reviewed and approved by:
14 JULY 1972

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Commander

ABSTRACT

The objective to obtain piloted-low-speed flight test data on the SV-5 re-entry configuration was accomplished by the X-24A in 28 flights over a 27-month time period. Sufficient data were obtained to allow detailed reporting in the areas of handling qualities, performance, stability derivatives, flight loads, flight control system, unpowered landings, vehicle system operation, and mass characteristics. Extensive use was made of a six-degree of freedom simulator and between-flight determination of stability derivatives in expanding the envelope incrementally to 1.6 Mach number. Unexpected and significant reductions in directional stability were experienced with the rocket engine on. Handling quality problems encountered during the flight test program were improved by minor alterations of the control system. The variability designed into the control system contributed significantly to the research program by providing different aerodynamic configurations for data analysis and in allowing improvements in flight characteristics.

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Table III
DIGITAL INPUT LINEUP

DATE 9-9-70 VEHICLE X-24A

BIT	CHAN	PARAMETER	BIN LIGHT OFF 0	BIN LIGHT ON 1
1	31	PITCH COMPARATOR OUTPUT NO 1	OK	MALFUNCTION
2	31	PITCH COMPARATOR OUTPUT NO 2	OK	MALFUNCTION
3	31	PITCH COMPARATOR OUTPUT NO 3	OK	MALFUNCTION
4	31	PITCH COMPARATOR OUTPUT NO 4	OK	MALFUNCTION
5	31	PITCH COMPARATOR OUTPUT NO 5	OK	MALFUNCTION
6	31	PITCH COMPARATOR OUTPUT NO 6	OK	MALFUNCTION
7	31	ROLL COMPARATOR OUTPUT NO 1	OK	MALFUNCTION
8	31	ROLL COMPARATOR OUTPUT NO 2	OK	MALFUNCTION
9	31	ROLL COMPARATOR OUTPUT NO 3	OK	MALFUNCTION
1	32	ROLL COMPARATOR OUTPUT NO 4	OK	MALFUNCTION
2	32	ROLL COMPARATOR OUTPUT NO 5	OK	MALFUNCTION
3	32	ROLL COMPARATOR OUTPUT NO 6	OK	MALFUNCTION
4	32	YAW COMPARATOR OUTPUT NO 1	OK	MALFUNCTION
5	32	YAW COMPARATOR OUTPUT NO 2	OK	MALFUNCTION
6	32	YAW COMPARATOR OUTPUT NO 3	OK	MALFUNCTION
7	32	YAW COMPARATOR OUTPUT NO 4	OK	MALFUNCTION
8	32	YAW COMPARATOR OUTPUT NO 5	OK	MALFUNCTION
9	32	YAW COMPARATOR OUTPUT NO 6	OK	MALFUNCTION
1	35	PITCH MODE SWITCH	ZERO GAIN	MANUAL
2	35	PITCH MALFUNCTION LIGHT - AMBER	OFF	ON
3	35	PITCH MALFUNCTION LIGHT - RED	OFF	ON
4	35	ROLL MODE SWITCH	ZERO GAIN	MANUAL
5	35	ROLL MALFUNCTION LIGHT - AMBER	OFF	ON
6	35	ROLL MALFUNCTION LIGHT - RED	OFF	ON
7	35	YAW MODE SWITCH	ZERO GAIN	MANUAL
8	35	YAW MALFUNCTION LIGHT - AMBER	OFF	ON
9	35	YAW MALFUNCTION LIGHT - RED	OFF	ON

Table III (Concluded)

DATE 9-22-70 VEHICLE X-24A

BIT	CHAN	PARAMETER	BIN. LIGHT OFF 0	BIN. LIGHT ON 1
1	36	KRA MODE SWITCH	MAN OR EMER	AUTO
2	36	KRA MODE SWITCH	AUTO OR EMER	MANUAL
3	36	KRA MODE SWITCH	AUTO OR MANUAL	EMER.
	36	MACH REPEATER MODE SWITCH	AUTO	MANUAL
	36	RUDDER BIAS - TOE OUT	TOE OUT	
6	36	RUDDER BIAS MODE SWITCH	AUTO	MANUAL
7	36	UPPER FLAP BIAS - DECREASE	DE-CREASE	
8	36	UPPER FLAP BIAS - INCREASE	IN-CREASE	
9	36	UPPER FLAP BIAS MODE SWITCH	MANUAL	AUTO
1	38	No 1 CHAMBER FIRE SWITCH	OFF	ON
2	38	No 2 CHAMBER FIRE SWITCH	OFF	ON
3	38	No 3 CHAMBER FIRE SWITCH	OFF	ON
4	38	No 4 CHAMBER FIRE SWITCH	OFF	ON
5	38	COCKPIT CAMERA - SINGLE FRAME PULSE	ON	OFF
6	38	ROLL No 1 SERVO SWITCH	AUTO OR MANUAL	OFF
7	38	RUDDER BIAS - TOE IN	TOE IN	
8	38	ROLL No 2 SERVO SWITCH	AUTO OR MANUAL	OFF
9	38	PARSON TAPE RECORDER	ON	OFF
1	39	No 1 IGNITER PRESSURE SWITCH	ON	OFF
2	39	No 2 IGNITER PRESSURE SWITCH	ON	OFF
3	39	No 3 IGNITER PRESSURE SWITCH	ON	OFF
4	39	No 4 IGNITER PRESSURE SWITCH	ON	OFF
5	39	CENTER FIN CAMERA - SINGLE FRAME PULSE	ON	OFF
6	39	YAW No 1 SERVO SWITCH	AUTO OR MANUAL	OFF
7	39	YAW No 2 SERVO SWITCH	AUTO OR MANUAL	OFF
8	39	PITCH No 1 SERVO SWITCH	AUTO OR MANUAL	OFF
9	39	PITCH No 2 SERVO SWITCH	AUTO OR MANUAL	OFF

Table IV

ONBOARD MAGNETIC TAPI

TAPE RECORDER SPEED 15 IPS	DATE 8 DEC 70	INS
TAPE RECORDER S/N	VEHICLE X-24A (SV-5)	
SHEET NO 1 OF 1	FLIGHT NO X-21-26	

TRACK / PIN NO	PARAMETER	AMP TYPE / S/N	AMP INPUT LEVEL (VOLTS)	TRANSDUCER TYPE / PIN	TRANSDUCER S/N	TRANSDUCER RANGE	J PAN'L	AMPLIFIER TYPE / S/N	CHAN	GAIN SET.
1 / A	Mic 04 (Upper Flap)	WB / 9	±2.5		1010	150 db			1	High
2 / B	Mic 01 (Cabin)	WB / 11	±2.5		1479	140 db			2	High
3 / C	Mic 02 (Upper Flap)	WB / 1001	±2.5		1021	150 db			3	High
4 / D	Mic 03 (Upper Flap)	WB / 1016	±2.5		1009	150 db			4	High
5 / E	25 KC Ref Oscil Time Code (IRIG-B Modulated)	DR / 91								
6 / F	Mic 05 (Upper Flap)	WB / 1017	±2.5		1017	150 db			5	High
7 / G	Mic 06 (Upper Flap)	WB / 1019	±2.5		1013	150 db			6	High
8 / H	Mic 07 (Upper Flap)	WB / 1020	±2.5		1014	150 db			7	High
9 / J	Vib 05 (Upper Rudder)	WB / 1021	±2.5		362	10 g			8	Low
10 / K	Vib 01 (Pilot Seat)	WB / 1022	±2.5		411	5 g			9	Low
11 / L	Vib 02 (Lower Flap)	WB / 1027	±2.5		401	10 g			10	Low
12 / M	Vib 03 (Upper Flap)	WB / 1025	±2.5		372	10 g			11	Low
13 / N	Vib 04 (Lower Rudder)	WB / 1030	±2.5		351	10 g			12	Low
14 / P	Mic 08 (Rear Bulkhead)	WB / 3	±2.5		1015	150 db			13	High

Table IV

ONBOARD MAGNETIC TAPE LINEUP

?

V-5)

6

INST ENGR W CLIFTON

DATE

TECH AMS 2/12/71

INSP

TAPE SPEED 15 IPS

N'L	AMPLIFIER BOX			SUB CALIB		VCO S AND CHASSIS				VCO OR WB AMPLIFIER			DR AMPLIFIER		
	TYPE SIN	CHAN	GAIN SET.	FREQ (CPS)	INPUT VOLT FOR 1.76 VRMS OUT	MOD	SIN POSN	I'PUT VOLT	IRIG BND	LOW	CENT	HIGH	VOLT FREQ	REF 25 kc	SIGN TOT
		1	HIGH	1000	153.2 mv					8100	13500	18900			
		2	HIGH	1000	6.7 mv					8100	13,500	18,900			
		3	HIGH	1000	64.5 mv					8,100	13,500	18,900			
		4	HIGH	1000	70.1 mv					8,100	13,500	18,900			
													1 VRMS 1000		
		5	HIGH	1000	52.5 mv					8100	13,500	18900			
		6	HIGH	1000	61.3 mv					8,100	13,500	18900			
		7	HIGH	1000	50.9 mv					8,100	13,500	18,900			
		8	LOW	1000	510.0 mv					8,100	13,500	18,900			
		9	LOW	1000	118.5 mv					8,100	13,500	18,900			
		10	LOW	1000	575.0 mv					8,100	13,500	18,900			
		11	LOW	1000	460.0 mv					8,100	13,500	18900			
		12	LOW	1000	456.0 mv					8100	13,500	18,900			
		13	HIGH	1000	40.1 mv					8,100	13,500	18,900			

2

Table V

INSTRUMENTATION ACCURACIES

Parameter	Processing Accuracy (pct)	Sensor Accuracy (pct)	Onboard PCM Accuracy (pct)	Power Supply Accuracy (pct)	Calibra Accura (pct
Angle of Attack[1]	0.1	1.0	0.25	0.5	0.25
Angle of sideslip[1]	0.1	1.0	0.25	0.5	0.25
Pitch rate	0.1	0.5	0.25	0.5	0.25
Roll rate	0.1	0.5	0.25	0.5	0.25
Yaw rate	0.1	0.5	0.25	0.5	0.25
Longitudinal acceleration	0.1	0.1	0.25	0.0	0.30
Lateral acceleration	0.1	0.1	0.25	0.0	0.25
Normal acceleration	0.1	0.1	0.25	0.0	0.25
Roll attitude	0.1	1.0	0.25	0.5	0.25
Pitch attitude	0.1	1.0	0.25	0.5	0.25
Hinge moments	0.1	---	0.25	0.5	----
Tail loads	0.1	---	0.25	0.5	---
Static pressure[2] (altitude)	0.1	1.5	0.25	0.5	0.25
Differential pressure[2] (altitude)	0.1	1.5	0.25	0.5	0.25
Upper rudder	0.1	1.0	0.25	0.1	0.30
Lower rudder	0.1	1.0	0.25	0.1	0.30
Upper flap	0.1	1.0	0.25	0.1	0.30
Lower flap	0.1	1.0	0.25	0.1	0.30

[1]Does not include corrections for upwash (reference 4).

[2]Does not include corrections for position error (reference 4).

Table V

NSTRUMENTATION ACCURACIES

Sensor ccuracy (pct)	Onboard PCM Accuracy (pct)	Power Supply Accuracy (pct)	Calibration Accuracy (pct)	RMS (pct)	Range (Parameter Units)	RMS (Parameter Units)
1.0	0.25	0.5	0.25	1.28	40 deg	.65 deg
1.0	0.25	0.5	0.25	1.25	20 deg	.33 deg
0.5	0.25	0.5	0.25	0.80	0 to 40 deg/sec	.3 deg/sec
0.5	0.25	0.5	0.25	0.80	60 deg/sec	.5 deg/sec
0.5	0.25	0.5	0.25	0.80	40 deg/sec	.4 deg/sec
0.1	0.25	0.0	0.30	0.41	1.0 g	.0041 g
0.1	0.25	0.0	0.25	0.38	2.0 g	.0076 g
0.1	0.25	0.0	0.25	0.38	4.0 g	.0152 g
1.0	0.25	0.5	0.25	1.17	180 deg	2.1 deg
1.0	0.25	0.5	0.25	1.17	90 deg	1.1 deg
---	0.25	0.5	----	----	---	---
---	0.25	0.5	----	----	---	---
1.5	0.25	0.5	0.25	1.62	230 psf	3.73 psf
1.5	0.25	0.5	0.25	1.62	80 psf	1.3 psf
1.0	0.25	0.1	0.30	1.08	50 deg	.54 deg
1.0	0.25	0.1	0.30	1.08	20 deg	.23 deg
1.0	0.25	0.1	0.30	1.08	60 deg	.65 deg
1.0	0.25	0.1	0.30	1.08	40 deg	.43 deg

e 4).

reference 4).

Table VI
PCM GROUND MONITORED PARAMETERS

TELEMETRY MONITOR ROOM

VEHICLE X-24A FLIGHT NO. X-23-34 DATE 2 June 71

SANBORN NO. 1

	L1		L2		L3		L4		L5	
CHANNEL										
PARAMETER										
RANGE										
OCTAL										
S.F. COUNT/DAC.										
COUNTS-MF/SF										

	M1		M2		M3		M4		M5	
CHANNEL										
PARAMETER										
RANGE										
OCTAL										
S.F. COUNT/DAC. NO.										
COUNTS-MF/SF										

1		2		3		4		5		6		7		8	
CH60 - CH70		47		34 + 46		60 + 70		48		52		42		59	
δ_{a_R}		β		α		α		α Boom		Ay Pilot		RH UP Rud		Ax	
-40°	+40°	+5°	-5°	10°	50°	0°	25°	+15°	5°	-0.5	+0.5	12.5°	-1.5°	+.5	.5
δ_{a_L}		NL	NR	δ_{e_R}		δ_{e_L}				LT	RT	LT	RT	FWD	AFT
5mm	5mm			10mm			25mm	10mm					10mm		
		254	526					663	166	415	763	024	626	764	415
			47						48		52		42		59

SANBORN NO. 2

	Y1		Y2		Y3		Y4		Y5	
CHANNEL	SC 16		SC 17		SC 18		43		44	
PARAMETER	Kq		Kp		Kr		LH RUD BIAS		RH RUD BIAS	
RANGE	2.1	4.0	2.1	4.0	2.1	4.0	7.2%	1.3	6.4%	0.[illegible]
OCTAL	200	400	200	400	200	400	200	400	200	400
S.F. COUNT/DAC. NO.		82		83		84		43		44
COUNTS-MF/SF	21	0	25	0	29	0				

	Z1		Z2		Z3		Z4		Z5	
CHANNEL	SC9		SC10		SC11		SC 26		SC 27	
PARAMETER	PITCH TRIM		ROLL TRIM		YAW TRIM		L/H FLAP BIAS		R/H FLAP BIAS	
RANGE	0 [illegible]	1.5 [illegible]	.38 L"	.06 [illegible]	.39 L"	.05 R	17°	31.2°	17°	31.5°
OCTAL	200	400	200	400	200	400	200	400	200	400
S.F. COUNT/DAC. NO.		69		73		77		92		93
COUNTS-MF/SF	73	3	77	3	1	0	61	0	65	0

1		2		3		4		5		6		7		8	
56		63		66		51		64		68		24		67	
PITCH RATE		#2 PITCH SERVO		#1 ROLL SERVO		ROLL RATE		#2 ROLL SERVO		#1 YAW SERVO		YAW RATE		#2 YAW SERVO	
+10°/s	-10°/s	+0.5"	-0.5"	-0.5"	+0.5"	-10°/s	+10°/s	-.2	+0.2	-0.5"	+0.5"	-10°/s	+10°/s	-0.5"	+0.5"
NU	ND	NU	ND	LT	RT	LT	RT			LT	RT	LT	RT	LT	RT
								INDENT 15mm	INDENT 15mm						
510	270	713	027	021	750	262	512	544	247	763	036	[illegible]	575	761	071
	56		63		66				64		68		24		67

SANBORN NO. 3

1		2	
SC72		SC 7[illegible]	
#1 BATT		#2 B[illegible]	
0	350A	0	+[illegible]
	15mm		10[illegible]
400	742	400	7[illegible]
	1		
5	3	9	[illegible]

CO[illegible]

C1		C2	
76		71	
H2O2 PRESS		LH RKT [illegible]	
20 psi	435	13 psi	2[illegible]
400	600	400	6[illegible]
	76		

D1		D2	
SC68		72	
CON BOX TEMP		R/H RKT [illegible]	
-2	-24	12 psi	
400	600	400	
	86		
69	2		

S.B. #10 [illegible] 5

SC52		SC5[illegible]	
1.0% MAN PR		AL MAN[illegible]	
0	4.00	0	
372	741	372	
	22		
05	2	13	

1		2	
SC37		SC3[illegible]	
NO1 CH PR		NO2 CH[illegible]	
100	500	100	
10mm 44[illegible]	117	10mm 450	
	16		
25	1	29	

ED PARAMETERS

ONITOR ROOM

SANBORN NO. 3

	N1		N2		N3		N4		N5	
CHANNEL	SC49		SC50		S[illegible]		SC19		34+46	
PARAMETER	#1 HYD		#2 HYD		KRA LPT		MACH RIP		2	
RANGE	0	1700	0	1700	2.1	1.5	1.2	1.65	Seu	
OCTAL	400	600	400	600	400	600	400	600	-10	-50
S.F. COUNT/DAC. NO.		20		26		65		85		
COUNTS-MF/SF	73	1	77	1	69	3	33	0		

	P1		P2		P3		P4		P5	
CHANNEL	SC 34		SC 35		SC 36					
PARAMETER	#1 BATT VOLT		#2 BATT VOLT		EQUIP	BATT VOLT				
RANGE	0	20v	0	20v.	0.2	21V.				
OCTAL	400	600	400	600	400	200				
S.F. COUNT/DAC. NO.		100		6		14				
COUNTS-MF/SF	13	1	17	1	21	1				

1		2		3		4		5		6		7		8	
SC72		SC73		SC74		SC75		28		SC5		MF 31		62	
#1 BATT		#2 BATT		EQUIP BATT		INST BATT		ROLL RATE		MACH SENSOR		SAS STATUS		#1 PITCH SERVO	
0	350A	0	400	0	150	0	50A	-10%/s	+10%/s	0.7	1.7			+0.5"	-0.5"
				2.5A/mm				(SAS)						NU	ND
	15mm		10mm												
400	742	400	774	400	677	400	526	525	251	664	461	000	777	73[illegible]	0[illegible]
	1		5		9		13		88		53		39		62
5	3	9	3	13	3	17	3			57	3				

CONSOLE METERS

C1		C2		C3		C4		C5	
76		71		SC55		SC56		SC64	
H2O2 PRESS		LH RKT PR		#1 He PRES		#2 He PRES		NOZZLE TEMP	
20 psi	435	13 psi	266	0 psi	2800	0 psi	2750	1000	1514
400	600	400	600	400	600	400	600	400	600
	76		71		28		30		89
				17	2	21	2	53	2

D1		D2		D3		D4		D5	
SC68		72		74		75			
CON BOX TEMP		R/H RKT PR		CONTROL GAS PRESS		GOV. BAL PR			
-2	-24	12 psi	293	18 psi	430	13 psi	435		
400	600	400	600	400	600	400	600		
	86		72		74		75		
69	2								

B.#10 [redacted] 5		[redacted] 6		[redacted] 7		[redacted] 8		[redacted]	
SC52		SC54		SC51		SC53			
LOX MAN PR		AL MAN PR		LOX TANK PR		ALC TANK PR			
0	600	0	500	20	100	20	100		
312	741	312	730	10mm 421-717		10mm 420	720		
	22		23		17		21		
05	2	13	2	1	2	9	2		

[redacted] 1		[redacted] 2		[redacted] 3		[redacted] 4		[redacted]	
SC37		SC38		SC39		SC40			
NO1 CH PR		NO2 CH PR		NO3 CH PR		NO4 CH PR			
100	500	100	500	100	500	100	500		
10mm 445	717	10mm 450	741	10mm 445	762	10mm 450	736		
	16		18		19		41		
25	1	29	1	33	1	37	1		

P.B. METERS

Q1		Q2	
34+46		SC57	
2		PITCH ANGLE	
Seu		+3°	+51
-10	-50	400	600
			31
.		25	2

Q3		Q4	
48		SC 5	
α IND		MACH SENSOR	
2.2	10	2.03	1.11
200	400	400	600
	48		53
		57	3

	KRA		α	
	0	50	-5	15
OCT	177	616	160	663

X-Y PLOTTER 1

X		Y	
SC5		48	
MACH SENS		α BOOM	
0.7	1.7	+15°	-5
		663	160
664	461		
	53	1	48
57	3		

Table VI (Concluded)

TE'.EMETRY ROOM

VEHICLE X-24A

FLIGHT NO. X-28-34

DATE 2 June 71

	1	2	3	4	5	6	7	8	
CHANNEL	2	4	10	7	8	11	6	3	
PARAMETER	HM-201	HM-205	HM-214	HM-210	RH LW FLAP	HM-215	HM-208	HM-203	
	LH UP RUD	LH LW RUD	H UP FLAP	LH LW FLAP	RH LW FLAP	RH UP FLAP	RH LW RUD	RH UP RUD	
RANGE	15K -10K	15K -10K	40K -10K	40K -10K	40K -10K	40K -10K	15K -10K	15K -10K	4
INDENT									
OCTAL	634 230	552 272	567 342	566 343	607 336	563 343	554 270	633 231	
S.F. COUNT/DAC. NO.	2	4	10	7	8	11	25	3	
COUNTS-MF/SF				1					

	1	2	3	4	5	6	7	8	
CHANNEL	SC37	SC38	SC39	SC40	SC64	SC69	SC52	SC54	
PARAMETER	No 1 CH PR	NO 2 CH PR	NO3 CH PR	NO4 CH PR	NOZZLE TEMP	LOX PR TEMP	LOX MAN PR	AL MAN PR	
RANGE	100 500	100 500	100 500	100 500	500 2000	-220 -320	0 500	0 500	
					°F				5
INDENT	5mm	10mm	13mm	10mm	10mm 10mm				
OCTAL	445 717	450 741	445 762	450 736	172 776	007 747	372 741	372 730	
S.F. COUNT/DAC. NO.	16	18	19	41	89	90	22	23	
COUNTS-MF/SF	25 1	29 1	33 1	37 1	53 2	73 2	65 2	13 2	

	1	2	3	4	5	6	7	8	
CHANNEL	SC58	51	SC13	SC14	24	48	52	47	
PARAMETER	BANK ANGLE	ROLL RATE	LAT STICK	RUD PEDAL	YAW RATE	α BOOM	AY PILOT	β	
RANGE	-50° +50°	-25°/s 25°/s	LT RT	LT RT	-10°/s +10°/s	+15 -5	-0.5 +0.5	5° -5°	
			2" 2"	3" 3"	LT RT		LT RT	NL NR	6
INDENT			20mm 20mm	10mm 10mm		10mm			
OCTAL	177 600	101 672	516 274	763 000	210 575	663 160	415 763	254 523	
S.F. COUNT/DAC. NO.	32	51	79	80	24	48	52	47	
COUNTS-MF/SF	29 2		9 0	13 0					

	1	2	3	4	5	6	7	8	
CHANNEL	48	56	SC12	60+70	55	SC 57	59	62	
PARAMETER	α BOOM	PITCH RATE	LONG STICK	2	AN	PITCH ANGLE	AX	#1 PITCH SERVO	
RANGE	+15 -5°	25°/s -25°/s	4" 6"	0° 25°	3 g -1	50° -50°	+.5 -.5	.5" -0.5"	
		NU ND	AFT FWD	SEL			FWD AFT	NU ND	7
INDENT	12mm		15mm 10mm	25mm	10mm				
OCTAL	663 160	663 114	641 004		764 415	575 165	764 415	734 [illegible]	
S.F. COUNT/DAC. NO.	46	56	78		55	31	54	62	
COUNTS-MF/SF			5 0			25 2			

	1	2	3	4	5	6	7	8	
CHANNEL	SC 8	60-70	64	SC 4	67	SC 11	SC 9	SC 10	
PARAMETER	KRA		#2 ROLL SERVO	ALTITUDE	#2 YAW SERVO	δr TRIM	δe TRIM	δa TRIM	
RANGE	0 50	-40° +40°	-.2 +.2		-.5" +.5"	0.4" 0.4"	1" 4"	0.4" 0.4"	
		SAL			LT RT	LT RT	AFT FWD	LT RT	8
INDENT		5mm 5mm	15mm 15mm	10mm		15mm 15mm	10mm 10mm	5mm 15mm	

COUNTS-MF/SF	27	2				9	3	13	0							

7

	1		2		3		4		5		6		7		8	
CHANNEL	48		56		SC12		60+70		55		SC 57		59		62	
PARAMETER	α BOOM		PITCH RATE		LONG STICK		2		An		PITCH ANGLE		Ax		#1 PITCH SERVO	
RANGE	+15	-5°	25°/s	-25°/s	4"	6"	0°	25°	3 g	-1	50°	-50°	+.5 g	-.5	.5"	-0.5"
			NU	ND	AFT	FWD	δeL						FWD	AFT	NU	ND
INDENT	12mm				15mm	10mm		25mm	10mm							
OCTAL	663	160	563	114	641	004			764	415	575	165	764	415	734	[illegible]
S.F. COUNT/DAC. NO.		46		56		78				55		31		54		62
COUNTS-MF/SF					5	0					25	2				

8

	1		2		3		4		5		6		7		8	
CHANNEL	SC 8		60-70		64		SC 4		67		SC 11		SC 9		SC 10	
PARAMETER	KRA				#2 ROLL SERVO		ALTITUDE		#2 YAW SERVO		δr TRIM		δe TRIM		δa TRIM	
RANGE	0	50	-40°	+40°	-.2	+.2			-.5"	+.5"	0.4"	0.4"	1"	4"	0.4"	0.4"
			δaL						LT	RT	LT	RT	AFT	FWD	LT	RT
INDENT			5mm	5mm	15mm	15mm	10mm				15mm	15mm	10mm	10mm	15mm	15mm
OCTAL	177	616			544	247	740	106	761	071	164	540	260	602	336	451
S.F. COUNT/DAC. NO.		65				64		3		67		77		64		73
COUNTS-MF/SF	69	3					53	3			1	0	73	3	77	3

9

	1		2		3		4		5		6		7		8	
CHANNEL	40		42		43		44		34		46		60		70	
PARAMETER	δr UL		δr UR		δR LL		δr LR		δe UL		δe UR		δe LL		δe LR	
RANGE	+15°	-25°	+25°	-15°	+10°	-10°	+10°	-10°	50°	10°	50°	10°	40°	0°	40°	0°
	LT	RT	LT	RT	LT	RT	LT	RT	UP	DN	UP	DN	DN	UP	DN	UP
INDENT	10mm			10mm						10mm		10mm	10mm		10mm	
OCTAL	656	022	024	626	131	765	761	053	106	677	104	677	036	704	030	714
S.F. COUNT/DAC. NO.		40		42		43		44		34		46		60		70
COUNTS-MF/SF																

ATTITUDE DISPLAY

142
404
347

	1		2		3		4		5		6		7		8	
CHANNEL			SC 1-7		27		47		SC 59		48		1-58		1-57	
PARAMETER			H-ALT		H DOT		β		ψ		α TRUE		ROLL ANGLE		PITCH ANGLE	
RANGE			0	1000	-300	+300	+2	337	18	273	7°	324	+32	514	+30	5
							0	400			12°	446	0	400	0	3
INDENT							-2	442			17°		-32	264	-32	252
OCTAL			400	001	006	776			200	400	22°	714				
S.F. COUNT/DAC. NO.				61				47		36		48		32		31
COUNTS-MF/SF			65	3					33	2			29	2	25	2

OSC-2

54		1-15	
H		H DOT	
0	5000'	-60	+60
		0 =	400
003	775	+60:	774
		-60:	303
	54		
		17	0

APPENDIX B

X-24A PRELAUNCH CHECKLIST

[illegible] 2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	[illegible]	[illegible]	[illegible]
	[illegible] wiring		
2	[illegible] check		
	a) [illegible] - X-24 [illegible]		
	b) Face Plate Heat		
	c) Cabin Air - B-52		
4	Radio [illegible] Sw - X-24	[illegible] Min to B-52 Eng Start	
5	Radio Check		
	a) Pri - [illegible]		
	b) Sec - [illegible].1		
	c) Guard - [illegible]		
6	Radio/Int Sw - B-52		
7	Ck [illegible] & Calib ([illegible])		
8	[illegible] Tk Sw - PRESS		
9	Cockpit Safety Pins removed ([illegible])		
10	Close & Lock Canopy		
	a) Canopy Lite - OUT		
11	Ram Air Door - CLOSE		
12	Ck Fire Ext - AUTO		

-1-

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
13	Canopy Defog Sw - AIR	B-52 Eng Start	
14	Gage Check:		
	a) #1 Helium ____		
	b) #2 Helium ____		
	c) Cont Gas ____		
	d) Gov Bal ____		
	e) Fuel Tank ____		
	f) LOX Tank ____		
	g) Ldg Gear ____		
	h) All Batt Bus ____		
	i) Reg O_2 ____		
	j) O_2 Cyl ____		
	k) X-24 Air ____		
	l) B-52 Air ____		
15	Rel Lock Set Lite-ON & Rel Press Low Lite OUT		
16	Ready to TAXI	Ready to TAXI	Ready to TAXI
17	Radar Sw - ON	Taxi	Radar Sw - ON
18	Bio-Med Sw - ON	Line up on Rwy	
19	Visor-ON (Set Heat)		

-2-

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	Erect Sw-ON/OFF	Brake Release	
2	Cycle Hydraulics	Takeoff	
3	Canopy Defog Sw-HEAT	Climb Pattern	
4	Pump Heater-ON		
5	Winds Aloft-NASA 1		
6	Verify Cabin Press at 18,000 ft ([illegible])		
7	Radio/Int Sw - X-24		
8	Radio Ck-Pri/Sec/Grd		Start LOX Top-off at 30K
9	Radio/Int Sw - B-52		
10	KRA Sw-AUTO		
11	NASA 1 call 35 Min to Launch	35 Minutes	
12	Surface Winds-NASA 1		
13	Chase A/C check Windshield Heat-HIGH		

-3-

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	Verify SAS Gains Kp 3 Kq 4 Kr 5	30 Minutes	
2	Calibrate		
3	Cal Press Alt ____		
4	X-24 Air Press ____		
5	B-52 Air Press ____		
6	Face Plate Heat-LOW		
7	3&4 Hyd Pump Sws-ON Low Press Lites-OUT #1 Hyd Press ____ #2 Hyd Press ____		
8	SAS Mode Sws-(3)MAN		
9	Ck all C/B's - IN except VEH SEL & BRAKE)		

-4-

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
10	Mach Repeater-AUTO	25 Minutes	
11	Flap Mode Sw-AUTO		
12	Read:		
	α ____		
	A/S ____		
	Alt ____		
	Ind Mach ____		
	Mach Rep ____		
	δu ____		
	δL ____		
	δRB ____		
	KRA ____		
13	Controls Check:	20 Minutes	
	a) Flap Mode Sw-MAN		
	b) Rudder Mode Sw - AUTO		
	c) Mach Repeater-MANUAL - Set 1.1		
	d) KRA Mode Sw-MAN		

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2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
	e) Cycle Emer Flap Sw (35° - 30° - 3[illegible]°)		
	f) Flap Bias Sw-OPEN (-40 δu 0 δr)	Chase Verify	
	g) Flap Bias Sw-CLOSE (+12 δu -10 δr)		
	h) Upper Flaps Set at (+40 δu 0 δr)	Chase Verify	
	i) Rudder Mode Sw - MANUAL		
	j) Rudder Bias Sw - Toe In (-10°)		
	k) Rudder Bias Sw - Toe Out (0 °)		
	l) Set Rudder Bias (0 °)		
	m) Rudder Mode Sw - AUTO		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
14	Stick		
	a) Full Fwd		
	b) Full Aft		
15	Stick Trim		
	a) Check Fwd Aft		
	b) Trim Set at 26 °	Chase Verify	
16	Aileron Trim		
	a) Ck Right, Left		
	b) Trim Set ___ °	Chase Verify	
17	Rudder Pedals		
	a) Full Rt		
	b) Full Lt		
18	Yaw Trim		
	a) Ck Right/Left		
	b) Trim Set 0 °	Chase Verify	
19	KRA Sw - INCREASE to 50 %		
20	Move Stick	Chase Verify	
	a) Full Rt ______ δR		
	b) Full Lt ______ δR		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
21	KRA Sw - DECREASE to 0%		
22	Move Stick Full Right/Left Observe no rudder	Chase Verify	
23	KRA Mode Sw - EMER		
24	Move Stick Full Right/Left Observe no Rudder Motion	Chase Verify	
25	KRA Sw - INCREASE to 50 %		
26	Move Stick		
	a) Full Rt _____ δR		
	b) Full Lt _____ δR	Chase Verify	
27	KRA Mode Sw - AUTO		
28	Verify	Chase Verify all trim	
	a) Mach Rep MANUAL 1.1		
	b) Flap Mode Sw-MAN		
	c) Rudd Mode Sw-AUTO		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
29	SAS Servo Sw(3)-AUTO	[illegible] Minutes	
30	Set SAS Gains Ki [illegible] Kp [illegible] Kr [illegible]		
31	SAS Check		
	a) SMRF Sw - [illegible]		
	b) Ck SAS Lite		
32	Torque Gyros		
	a) Ck SAS Lites OUT		
33	Pitch, Roll, Yaw #1 Servos - OFF		
34	Torque Gyros		
	a) Ck 3 Amb Lts ON		
35	Pitch, Roll, Yaw #2 Servos - OFF		
36	Torque Gyros		
	a) Ck 3 Red Lts ON		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
37	Set SAS Gains Ki 1 Kp 1 Kr [illegible]	15 Minutes	
38	SAS Servo Sw(3)-AUTO		
39	Reset SAS Lites		
40	Set SAS Gains Ki 3 Kp 4 Kr 5		
41	Torque Gyros		
	a) Ck SAS Lites OUT		
42	Verify SAS Mode Sws (3) - MANUAL		
43	a) #2 Hyd Sw - OFF	14 Minutes	
	b) #1 Hyd Sw - ON		
	c) #4 Hyd Sw - OFF		
	d) #3 Hyd Sw - ON		
	e) #1 Hyd Press ___		
	f) #2 Hyd Press ___		
44		13 Minutes B-52 Pitch & Yaw Pulse	
45	Erect Sw - ERECT	B-52 Wings	
46	Fast Erect Sw - ON	Level	

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
47	Verify Trim Setting	11 Minutes	
	a) Upper Flaps 40°		
	b) Lower Flaps 26°		
	c) Aileron 0		
	d) Rudders 0		
	e) Rudder Bias 0	Chase Verify	
48	Read Pressures	10 Minutes	
	a) #1 Helium _____		
	b) #2 Helium _____		
	c) Cont Gas _____		
	d) Gov Bal _____		
	e) Fuel Tnk _____		
	f) LOX Tnk _____		
	g) Ldg Gear _____		
49	Pump Htr Sw - OFF/ON		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
50	Erect Sw - CUTOFF	9 Minutes	
51	Fast Erect - OFF		
52	KRA Mode Sw - MAN		
53	KRA Sw - INCREASE to 50 %		
54	Throttle ON-OFF	8 Minutes	
	a) NASA 1 Verify	B-52 Start Turn	
55	Radio Sw - X-24	7 Minutes	
56	Radio Check		
	a) Pri - 275.9		
	b) Sec - 268.1		
	c) Grd - 279.9		
	d) Pri - 275.9		
56	e) Chase A/C Check Windshield Heat	6 Minutes	

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
57	DC Power Sw-BATTERY	5 Minutes	
58	Ck Emer Batt Lite - OUT		
59	a) #1 Hyd Sw - OFF		X-24 Adapter Pwr Sw - OFF
	b) #2 Hyd Sw - ON		Ammeters-ZERO
	c) #3 Hyd Sw - OFF		
	d) #4 Hyd Sw - ON		
	e) #1 Hyd Press ____		
	f) #2 Hyd Press ____		
60	Bus Loads #1 ____		
	#2 ____		
	#3 ____		
	#4 ____		
61	Reset SAS Gains		
	Kq 5 Kp 5 Kr 5		
	a) SMRD Sw - ON		
	b) Ck SAS Lites - OUT		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
62	Torque Gyros	4 Minutes	
	a) Ck SAS Lites-OUT	210 KIAS	
63	#1 SAS Servos - OFF		
64	Torque Gyros		
	a) Ck 3 Amb Lts - ON		
65	#2 SAS Servos - OFF		
66	Torque Gyros		
	a) Ck 3 Red Lts-ON		
67	Reset SAS Gains		
	Kq 3 Kp 4 Kr 5		
68	SAS Servo Sws (6) - AUTO		
69	Reset SAS Lites		
70	Torque Gyros		
	a) Ck SAS Lts-OUT		

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
71	Oxy Sel - X-24	3 Minutes	
	a) O_2 Reg Press ____		
	b) O_2 Cyl Press ____	200 KIAS	
72	Cabin Air Sw - X-24		
	a) X-24 Air ____		
	b) Cab Alt ____		
	c) Verify Canopy Defog Sw - HEAT		
73	Fwd Canopy Htr - ON		
74	Suit Vent - LOW		
75	Read Pressures		
	a) #1 Helium ____		
	b) #2 Helium ____		
	c) Cont Gas ____		
	d) Gov Bal ____		
76	Erect Sw - ERECT		
77	Fast Erect - ON		
78	Recheck Trim Setting	Chase Verify	

2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
79	Pump Htr Sw - OFF	2 Minutes	LOX Topoff-Comp
80	Prop Supp - ON	190 KIAS	Beacon - OFF
81	Fuel & LOX Tnk-PRESS		
82	Verify Tnk PRESSURE (45 ± 5)		
83	Ck Release Press Low Lite - OUT		

2/1 1

O	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
4	NASA 1 Call	70 Seconds	
5	Start Clock	1 Minute 185 KIAS	
6	Read #1 & #2 Sources		
7	Ck SAS Lites - OUT		
8	Ck Hdg, α , β		
9	Eng Mstr - ON	45 Seconds	
0	Erect Sw - CUTOFF		
1	Fast Erect - OFF		
2	Systems OK - NASA 1	30 Seconds	Cameras - ON
3	Release C/B - IN	Chase Verify	
4	CAMERA/RECORDER - ON	Prime	
5	Igniter Test - RESET	15 Seconds	
6	LAUNCH		
	ALTERNATE LAUNCH PROCEDURE		
	Pilot call for Alt Launch	Launch Master Arm Launch Sw-L-CH	

10 MINUTE HOLD AT 6 MINUTES TO LAUNCH 2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	SAS Act (6) - OFF		
2	Hyd Pumps - OFF		
3	RTN TO 7 MIN POINT		
4	#1 & #3 Hyd Pumps-ON	7 Minutes	
	Low Press Lites - OUT		
	#1 Hyd Press ______		
	#2 Hyd Press ______		
	SAS Act (6) - AUTO		
	Read:		
	#1 Helium ______		
	#2 Helium ______		
	Ldg Gear ______		
	O_2 Cyl ______		
	X-24 Air ______		
	B-52 Air		
7	RETURN TO 7 MINUTE POINT ON CHECKLIST		

[illegible]ORT [illegible]TER [illegible] S T[illegible] [illegible]AUNC[illegible] 2/ /71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	Release C/B - PULL		B-52 Camera-OFF X-24 Adapter Pwr Sw - ON
2	DC Pwr Sel - B-52		
3	SAS Act (6) - OFF	Descent for Ldg RW 4 w/fuel schedule for left wing low	
4	Eng Master - OFF		
5	Prop Supply - OFF		
6	O_2 Sel - B-52		
7	Cabin Air - B-52		
8	Camera/Recorder - OFF		
9	All Hyd Pumps - OFF		
10	Canopy Defog Sw - AIR		
11	Radio/Int Sw - B-52		
12	LOX & Fuel Jett ____	Chase Verify	
13	LOX & Fuel Tank Sws-OFF		
14	Jett Sws - OFF		
15	KRA Mode Sw - MANUAL		

AFTER LANDING OR IN PARKING AREA MATED 2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	Throttle - OFF		
2	Cockpit Camera - OFF		
3	Recorder-OFF		
4	Calibrate		
5	SAS Servo Sws(6)-OFF		
6	All Hyd Pumps - OFF		
7	Canopy Defog - OFF		
8	Call out:		
	a) Cont Gas ______		
	b) Gov Bal ______		
	c) #1 Helium ______		
	d) #2 Helium ______		
	e) Ldg Gear ______		
	f) O_2 Cyl ______		
	g) Cabin Air ______		
9	Radar Sw - OFF		
10	Radio - OFF		
11	Gyro Pwr Sw - OFF		
12	Attitude Inv Sw - OFF		
13	Install Safety Pins(3)		
14	Oxy Sel - OFF		
15	Cabin Air - OFF		

EMERGENCY LAUNCH PROCEDURES 2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	Announce Emergency		
2	DC Pwr Sw - BATT	If time permits decel to 185 KIAS & pick up headings for launch to Emer Runway	X-24 Adapter Pwr Sw - OFF
3	Reset Emer Batt Sws		
4	2 & 4 Hyd Pump Sws-ON		
5	Prop Supply - ON		
6	LOX & Fuel Tks-PRESS		
7	Eng Master - ON		
8	SAS Servo Sws(6)-AUTO		
9	Cabin Air Sw - X-24		
10	Radio Sw - X-24		B-52 & Pylon Camera - ON
11	Oxy Sel - X-24		
12	Release C/B - IN		

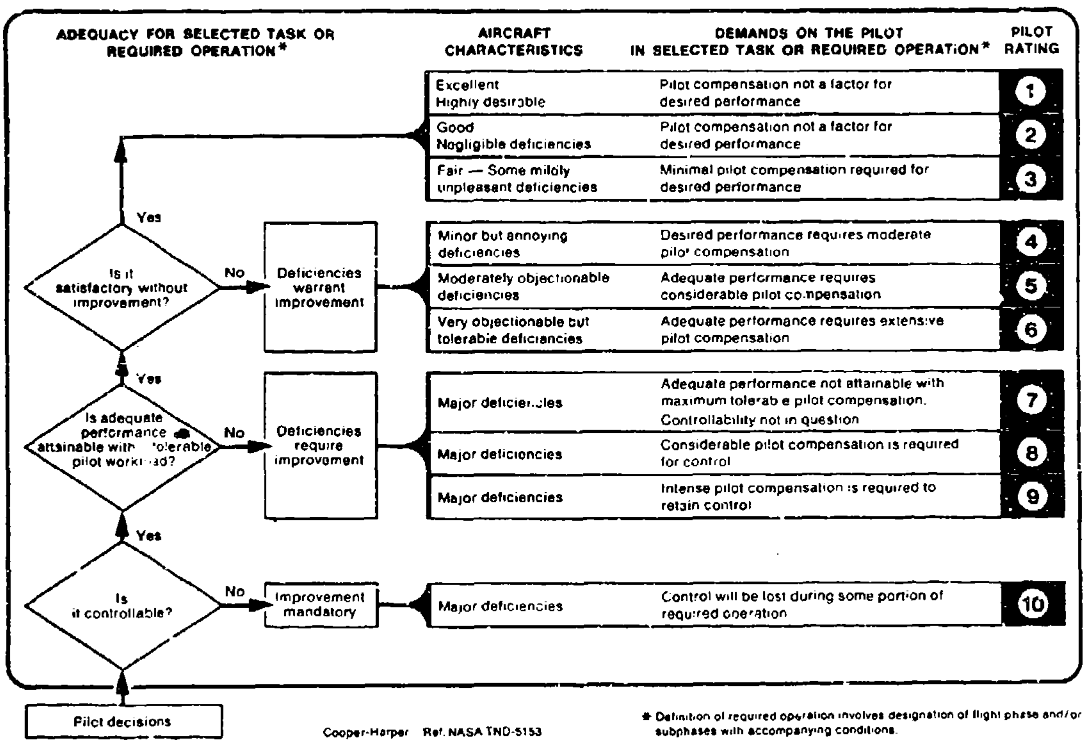
EMERGENCY LAUNCH PROCEDURES (cont) 2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
13	Mach Repeater Man 1.1		
14	Ck Surface Pos:		
	a) Rudders 0		
	b) Upper Flaps 40		
	c) Lower Flaps 26		
	d) Rudder Bias 0		
15	LAUNCH		
16	Suit Vent - LOW		
17	Fwd Canopy Defog Sw - ON		
18	Ck #1 & #2 Hyd Sys Press		
	ALTERNATE LAUNCH PROCEDURE		
1	Pilot call for Alternate Lnch	Launch Master Arm	
2		Launch Sw-LNCH	

X-24 PILOT EJECTION WHILE MATED TO B-52 2/11/71

NO	X-24 PILOT STATION	B-52 PILOT STA	LAUNCH OPER STA
1	Announce Emergency	Decel to 185 KIAS prior to launch of X-24 if possible	
2	Position Feet		
3	Pull Green Apple		
4	Pull Canopy Jettison Handle		
5	Head firm against head rest		
6	Grip both handles & squeeze		
7	Pull handles until locked	Launch Mast ON Launch X-24 Report crew status & plan of action	Verify separation

APPENDIX III
PILOT RATING SCALE



APPENDIX IV
FLIGHT 23 FLIGHT REQUEST

10 February 1971

Flight No: X-23-28

Scheduled Date: 17 February 1971

Pilot: John Manke

Purpose: 1. Envelope Expansion to 1.5 Mach No.

2. Lateral-directional derivative determination

3. Longitudinal trim and L/D data with 40° upper flap at 0° rudder bias

Launch: Cuddeback; Mag heading 209° + Crosswind Correction Angle. 45,000 feet, 185 KIAS; Flap Bias "Manual", Upper Flaps = -40°, Lower Flaps + 26°, Rudder Bias "AUTO", Upper & Lower Rudders = 0°. SAS Gain 3, 4, 5, Mach Repeater "MANUAL" = 1.1, KRA "MANUAL" = 50%, Hyd Pumps 2 & 4 on

Landing: Rogers Rw 33

B-52 Track: Lifting Body Track #8

Item	Time	Alt	A/S	α(ind)	Mn	Event
1		45	185	4	.69	Launch, light 4 chambers, trim to 17°α. Pitch Gain to 5.
2	22	42	260	17	.90	Max Mach during rotation
3	44	46	220	17	.84	θ = 37°. Maintain θ = 37°

Item	Time	Alt	A/S	α(ind)	Mn	Event
4	50	48	205	15	.82	KRA to "AUTO".
5	78	57	185	14	.88	At 57K, pushover to 10°α
6	112	66	215	10	1.20	At 66K, pushover to 7°α
7	124	68	235	7	1.38	Perform rudder and aileron doublets
8	133	69	265	7	1.5	Shutdown, retrim to 11°α and perform rudder and aileron doublets at Mach ≃ 1.35
9	143	69	215	11	1.24	Perform pushover-Pullup, 5° to 12°α. Return to 11°α
10	173	61	180	11	.92	At Mach T = .92. Pullup to 14°α, perform rudder and aileron doublets and evaluate handling qualities
11	204	49	195	14	.80	Return to α ≃ 10° and turn to down wind
12	237	36	225	10	.70	Perform pitch damper off pitch pulse. SAS gains to 3,2,5. Mach Repeater to .3
13	255	33	215	10	.62	Perform Pushover-Pullup 5° to 17°α, Return to 10°α

Item	Time	Alt	A/S	α(ind)	Mn	Event
14	280	26	210	10	.52	Perform pushover-pullup, 5° to 17°α, return to 10°α
15	290	24	210	10	.48	Change configuration to 13° upper flap bias.
16	303	19	200	10	.44	Low key. #1 & #3 hydraulic pumps on.
17						Perform aileron dublet at 5°α

NOTES:

1. Pitch attitude null at 37°

2. Empty weight = 5882 lbs — gear up c.g. 56.1%
   Launch weight = 11446 lbs — gear up c.g. 55.8%
   Landing weight = 6460 lbs — gear down c.g. 56.4%
   Thrust/Chamber = 2167
   Burn Time 4 chambers = 135 sec

3. Power on base drag coefficient = -.02

Ground Rules for NO LAUNCH:

1. Radio, radar, PCM failure

2. Electrical or SAS malfunction

3. A/S, altitude, Mach or angle of attack malfunction

4. Any control system malfunction

5. Loss of cabin pressure

6. Turbulence below 10K in excess of moderate

7. Surface winds greater then 15 KTS or crosswind greater than 10 KTS

8. Less than 3 good igniters after 2 attempts

9. Failure of engine control box heater

Alternate Situations After Launch:

	Failure	Action
1.	Radio, radar, PCM	Proceed as planned
2.	Total damper failure	Fly 2 chamber profile (item 7) Yaw failure reduce roll gain to 1. Roll failure reduce yaw gain as necessary
3.	A/S, altitude, Mach	Proceed as planned using α, θ and time for profile control
4.	Attitude System	Proceed as planned. Use 14°α instead of 37°θ at 44 sec
5.	Delayed Engine Light	Proceed as planned
6.	Only One Chamber Operates	Vector for RW 01 Cuddeback shutdown chamber, jettison, change configuration
7.	Only Two Chambers Operate	Rotate at 17°α, retract upper flaps to 35°. Fly 180-220 KT profile. Change configuration to 30° upper flap at .7 Mach No. Shutdown on NASA I call ($\simeq$ 250 sec)
8.	Only Three Chambers Operate	Maintain 20°α at 58K pushover to 11°α. Burnout at 1.1 Mach No. (170 sec) or shutdown on NASA I call. Proceed with subsonic data maneuvers.

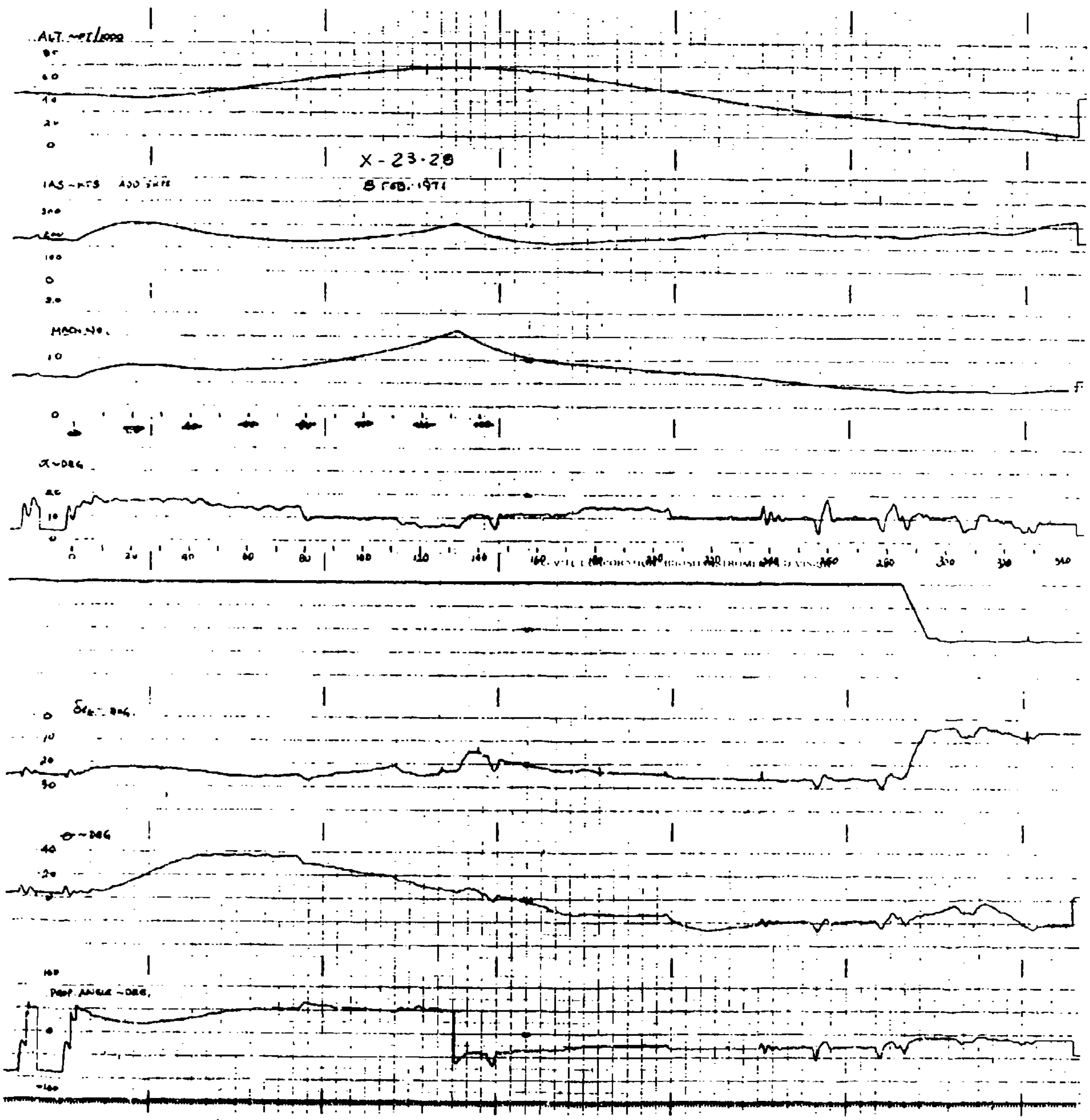
9.	KRA "AUTO" Failure	Set to manual 50% and porceed as planned-after configuration change set to 20%. If "MANUAL" mode inoperative - switch to "EMER" position and set to above values
10.	Angle of Attack	Fly 2 chamber profile (item 7) rotate at 1.1g to 200 KTS. KRA MANUAL, proceed with item 9.

11. Premature Engine Shutdown

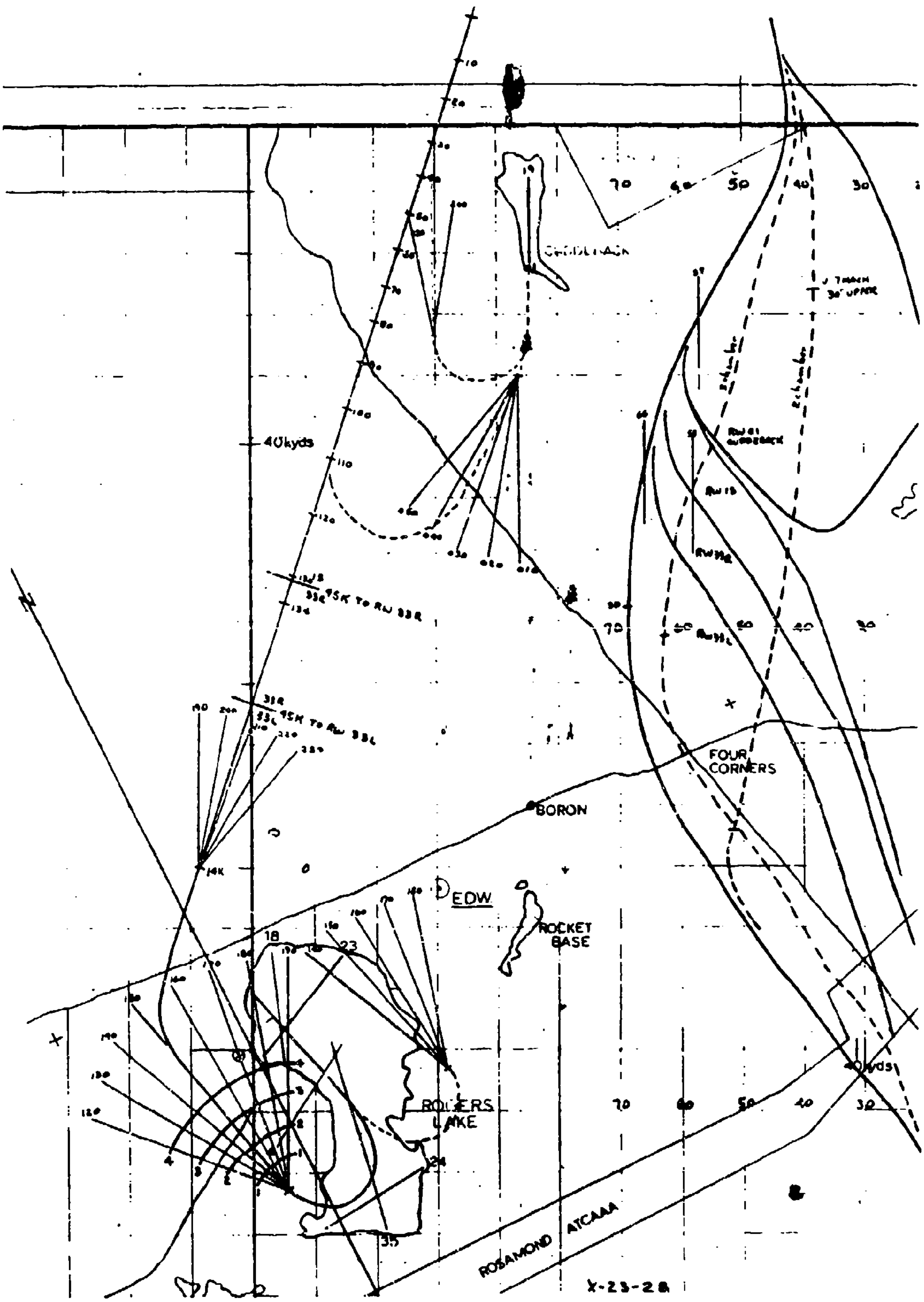
0 - 80 sec RW 01 Cuddeback
80 - 90 sec RW 15 Rogers
90 - 100 sec RW 33 Rogers (Right Hand Turn)
100 - up sec RW 33 Rogers (Left hand Turn)

Robert G. Holy
ROBERT G. HOLY

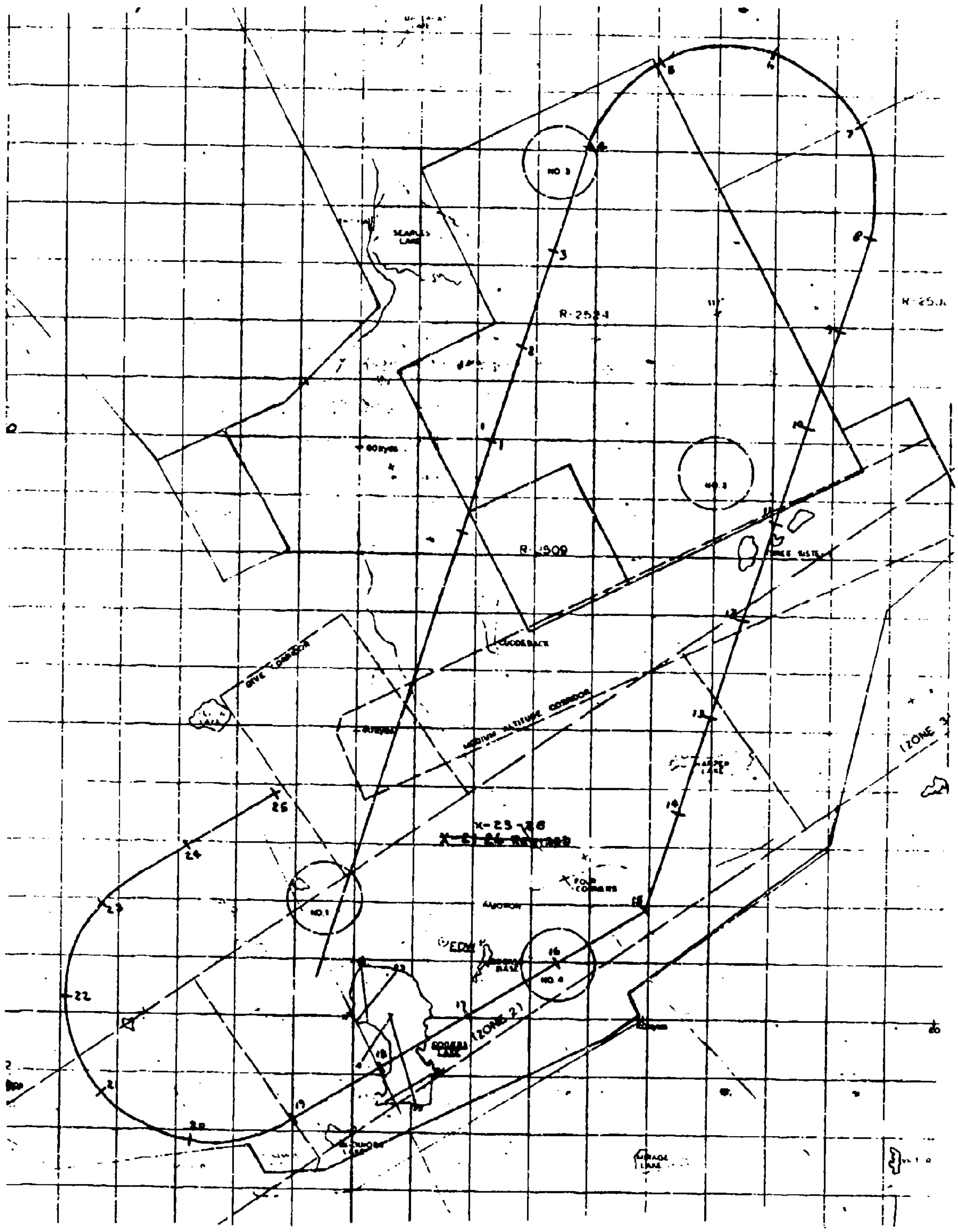
Garrison P. Layton Jr.
GARRISON P. LAYTON, JR.



ALT ~FT/1000
X-23-28
8 FEB. 1971
IAS~KTS
MACH NO.
α~DEG
θ~DEG
PROP. ANGLE ~DEG.



40kyds
ROGERS LAKE
BORON
FOUR CORNERS
EDW
ROCKET BASE
ROSAMOND
ATCAAA
X-23-28



R-2524
R-2508
NO. 3
NO. 2
NO. 1
NO. 4
CUDDEBACK
DIVE CORRIDOR
MEDIUM ALTITUDE CORRIDOR
X-23-26
FOUR CORNERS
EDW
ROGERS LAKE
(ZONE 2)
(ZONE 3)
MIRAGE LAKE

APPENDIX V
X-24A FLIGHT LOG

Total No. of flights	28
Glide flights	10
Powered flights	18
No. of planned captive flights	2
No. of flight aborts	5
Aborts due to weather	2
Aborts due to aircraft	1
Aborts due to instrumentation	2
No. of flight day cancellations	18
Cancellations due to weather	15
Cancellations due to aircraft	2
Cancellations due to instrumentation	1
Total flight time	2 hr, 54 min, 28 sec
Total time from launch to shutdown	51 min, 03 sec
Total time from shutdown to low key (plus gli flights)	1 hr, 13 min, 56 sec
Total time from low key to touchdown	49 min, 29 sec
Flights by Major Jerauld R. Gentry (total)	13
glide flights	8
Powered flights	5
Total flight time	1 hr, 9 min, 15 sec
Flights by John A. Manke (total)	12
Glide flights	1
Powered flights	11
Total flight time	1 hr, 26 min, 58 sec
Flights by Major Cecil W. Powell (total)	3
Glide flights	1
Powered flights	2
Total flight time	18 min, 15 sec
Maximum Mach number (Flt. 25 - Manke)	1.6
Maximum altitude (Flt. 19 - Manke)	71,400 ft
Longest flight Time (Flt. 28 - Manke)	8 min, 37 sec
Shortest flight time (Flt. 1 - Gentry)	3 min, 37 sec

X-24 LOG

DATE	FLIGHT NUMBER	PILOT	LAUNCH ALT/A/S	LAUNCH AREA	MAX MACH	MAX TRUE A/S KTS	MAX ALT	FLIGHT TIME	XLR-11 BURN TIME SEC.	LAND RUNWAY	REMARKS
4Mar69											
11Mar69	12	Taxi Runs with L/D rockets									Nose gear steering removed
12Mar69											
13Mar69											
2Apr69	B-52/X-24 mated taxi test										
4Apr69	X-1C-1	Gentry									Systems Check, Pylon Damping
17Apr69	X-1-2	Gentry	45/174	SOUTH ROGERS	.718	411	45	3:37.4	GLIDE	18	SAS gains 3-3-5, upper flaps at 21° thru flight. KRA C/B popped during flight, KRA stuck at 35°, L/D rockets used. Yaw amber SAS light came on after launch but was reset
8May69	X-2-3	Gentry	45/174	SOUTH ROGERS	.693	397	45	4:12.8	GLIDE	18	SAS gains for land. 3-4-3, upper flaps to 25° during flight and at 21° for land. Yaw amber SAS light came on twice but reset each time. Lower flaps rate limited on occasions. L/D rocket used.
8Aug69	X-A-4	Gentry									Aborted because of failure of SAS pitch red warning light and T/M SAS ground monitoring system - Pilot uncomfortable warm, several environmental system changes made
21Aug69	X-3-5	Gentry	40/175	SOUTH ROGERS	.58	332	40	4:29.9	GLIDE	17	Flight at 21° upper flap except for tests at 15°. SAS gains 3-4-6, dampers off tests. Launched 30 sec early, land RW17 L/D rockets used
29Aug69	X-A-6	Gentry									Aborted because of T/M SAS monitoring failure

X-24 LOG

DATE	FLIGHT NUMBER	PILOT	LAUNCH ALT/A/S	LAUNCH AREA	MAX MACH	MAX TRUE A/S	MAX ALT	FLIGHT TIME	XLR-11 BURN TIME	LAND RUNWAY	REMARKS
						KTS			SEC.		
9Sep69	X-4-7	Gentry	40/175	SOUTH ROGERS	.594	349	40	3:52.4	GLIDE	18	Flight at 21° upper flap except for tests at 15°. SAS gains 3-4-6, dampers off tests. Normal T/M SAS monitoring failed but alternate monitoring procedures had been established.
24Sep69	X-5-8	Gentry	40/175	SOUTH ROGERS	.596	344	40	4:16.5	GLIDE	18	Upper flap usage: 23° launch, test at 11°, pattern @ 18°, 23° landing. Rudder bias to -5° for test. SAS gains 3-3-7
15Oct69	X-A-9	Manke									Aborted because of clouds, rescheduled for 21 Oct based on battery turn around. Cancelled on 21 Oct because of rain
22Oct69	X-6-10	Manke	40/175	SOUTH ROGERS	.587	336	40	3:57.5	GLIDE	18	Upper flap: 21° launch, 30° test 22° land. SAS gain 3-2-7
13Nov69	X-7-11	Gentry	45/175	SOUTH ROGERS	.646	371	45	4:30.0	GLIDE	18	Upper flaps: 21° launch, 30° & 0° rudder test, 12° pattern, 19° land. SAS gain 3-2-7
25Nov69	X-8-12	Gentry	45/175	SOUTH ROGERS	.685	394	45	4:26.1	GLIDE	18	Upper flaps: 30° 10° rudder bias launch, 15° pattern, 12° land SAS gain 3-2-7
23Jan70	XLR-11 Run in A/C for first time										
20Feb70	X-2C-13										Propulsion system test, pylon damping, pwr flt check list
	X-A-13										Glide flt aborted because of instrumentation discrepancy between T/M A/C rates & surface positions thru SAS
24Feb70	X-9-14	Gentry	47/175	SOUTH ROGERS	.771	442	47	4:18.1	GLIDE	18	

X-24 LOG

DATE	FLIGHT NUMBER	PILOT	LAUNCH ALT/A/S	LAUNCH AREA	MAX MACH	MAX TRUE A/S	MAX ALT	FLIGHT TIME	XLR-11 BURN TIME	LAND RUNWAY	REMARKS
19Mar70	X-10-15	Gentry	40/175	PALMDALE	.865	496	44384	7:4.25	SEC. 155.3	18	First powered flt, standard flap config - 35° upper/0° rudder to 13° upper/-10° rudder, 2 chamber rotation, L/H tire badly worn
2Apr70	X-11-16	Manke	40/180	PALMDALE	.866	496	58693	7:15.4	152.3	18	3 chamber rotation, data at .8 Mach std flap config
22Apr70	X-12-17	Gentry	40/185	PALMDALE	.925	530	57600	6:47.5	134.4	18	4 chamber rotation, data at .85 Mach, std flap config
14May70	X-13-18	Manke	42/185	PALMDALE	.748	428	44590	8:32.5	254.3	18	Chambers 2&3 failed to light. Alternate profile flown
17Jun70	X-14-19	Manke	42/185	PALMDALE	.990	567	61032	7:12.4	128.4	18	35° upper flap flight, .9 Mach dampers off data, poor lateral control at 5°α, 50% KRA eval in pattern
28Jul70	X-15-20	Gentry	42/185	PALMDALE	.938	537	58144	6:28.3	124.6	18	35° launch, 40° upper flap tests, yaw gain 5, WALC not jettisoned
11Aug70	X-16-21	Manke	42/185	PALMDALE	.986	565	63947	6:53.1	138.9	18	40° upper flap launch, chamber #2 20 sec late in starting, roll gain 5, 50% KRA eval & landing
26Aug70	X-17-22	Gentry	42/185	PALMDALE	.694	392	41500	7:59.1	221.4	18	40° upper flap launch, two chamber profile flown. Fire damage in aft area during jettison
14Oct70	X-18-23	Manke	42/185	PALMDALE	1.186	681	67900	6:51.1	125.1	18	40° Upper flap launch, first supersonic flight, 270 kt approach
27Oct70	X-19-24	Manke	44/185	PALMDALE	1.357	780	71407	6:56.7	135.0	18	Upper flap approach, high cross wind landing
20Nov70	X-20-25	Gentry	45/185	PALMDALE	1.370	786	67589	7:12.1	121.4	18	Upper flap approach
21Jan71	X-21-26	Manke	45/185	CUDDEBACK	1.023	586	56977	7:41.6	194.0	33	First Cuddeback Launch, angle of attack gage failed, shutdown 2 chambers, flew alternate profile WALC burnout
4Feb71	X-22-27	Powell	45/175	SOUTH ROGERS	.659	377	45000	3:55.7	GLIDE	15	Powell's first flight-glide

DATE	FLIGHT NUMBER	PILOT	LAUNCH ALT/A/S	LAUNCH AREA	MAX MACH	MAX TRUE A/S	MAX ALT	FLIGHT TIME	XLR-11 BURN TIME	LAND RUNWAY	REMARKS
18Feb71	X-23-28	Hanke	45/185	CUDDEBACK	1.511	867	67456	7:26.8	137.4	33	
8Mar71	X-24-29	Powell	45/185	CUDDEBACK	1.002	574	56869	7:16.9	184.4	33	Powell's first powered flight High crosswind landing, Pylon O_2 QD remained with A/C after launch
29Mar71	X-25-30	Hanke	45/185	CUDDEBACK	1.60	900	70500	7:25.6	134.5	33	First flight with rudders toed out two degrees
22Apr71	X-A-31	Powell		CUDDEBACK							Abort due to high surface winds
12May71	X-26-32	Powell	45/185	CUDDEBACK	1.389	798	70947	7:2.7	143.5	33	Delayed engine light, auto flap operation, checkout of AV feedback
25May71	X-27-33	Hanke	47/190	CUDDEBACK	1.191	683	65268	8:8.3	189.6	33	Chamber #3 failed to light, 3 chamber profile flown with ALC burnout
4Jun71	X-28-34	Hanke	47/190	CUDDEBACK	.817	468	54373	8:37.2	264.5	33	Chambers #3 & #4 failed to light, 2 chamber profile flown.

MAJOR CONFIGURATION CHANGES

Prior to Flight	
X-2-3	Reduced rate KRA actuator installed, 3 amp KRA C/B installed, KRA C/B warning light relocated
	Flight cancelled on 6 & 7 May 69 because of clouds
X-A-4	Several cockpit changes, lower flap control horns modified to increase max surface rates, installed SAS zero gain mode switches, changed damping & gradient in stick for roll, changed KRA schedule to start from 6°α rather than 0°α, reduced travel of lower flap actuators by 50% & installed new orifices, installed center fin camera & belly camera - printed aft part of A/C. A/C to cal lab for A/S & alt calib, installed orifices in lower flap actuator servo valve, relocated actuator servo valve input rods from #1 to #2 hole, yaw SAS gyro was realigned.
X-5-8	140 lbs ballast removed from boattails, RH rudders rigged 1/8" inboard, aft pitch trim stop reset, upper flap stops at -11° to -24°, rudder bias stops -5° to -10° (toe in), fin camera to view PT side.
X-A-9	Upper flap stops at -15° & 30°, rudder bias fixed at -10°
X-7-11	Upper flap stops -12° to 30°, rudder bias stops 0° to -10°, stiffer spring in pitch, pitch stick to surface gearing reduced 15%
	Delays: 5 Nov 69 maded, 6 Nov cancel w/x, 7 Nov .41" rain
X-2C-13	Upper flap stops 35° to 13°, rudder bias programmed as function of upper flap in "auto" mode, aft pitch trim stop to allow +16° lower at 35° upper, KRA intercept for 0% from 6°α to 3°α, modify nose gear door, microballoon filler to LH upper flap, remove H meter install 3 "g" meter, preparations for powered flight, new lower flap hinge fittings, two 19 amp hour batteries installed, pitch SAS gyro relocated.
X-10-15	Upper flap stop moved to 40°, center fin camera removed
X-11-16	KRA stop moved from 40% to 50%
X-12-17	Installed new tip fin camera, LOX prime line TC installed
X-13-18	Increased stick gearing (pitch) by 15%, pitch SAS gearing change to keep same as before, double yaw gains for same switch position, increase pitch breakout forces by .5 pounds, cockpit camera to left side KRA to 0% at 0°α
X-14-19	Eng No 3 removed, # installed, eng control box heater installed
X-15-20	SAS inverters rewired, KRA slope vs α changed at Mach 1.2, lower flap bias stop changed from 19.4 to 24.2, installed new dual KRA motor, aft trim stop moved one inch aft

MAJOR CONFIGURATION CHANGES

Prior to Flight	
X-15-21	Increased roll breakout forces by one pound
X-17-22	Sun shield on canopy, AL skin putover LH upper flap, rudder bias schedule changed
X-18-23	Repaired fire damage, #2SV-5J upper flaps installed, installed engine S/N 3, instrumented engine parameters, engine mount repaired, removed two hyd batteries, LOX & fuel jettisoned tube modified, emergency flap bias switch installed, revised upper flap vs Mach schedule, installed A/S/Mach meter, T/C on #1 nozzle
X-19-24	Upper Flap stops removed
X-20-25	Installed new "O" rings & pistons in engine control box, modified KRA schedule f(Mach), removed tufts, mounted center fin camera to look at engine, replaced ADI platform, changed altimeters.
X-21-26	Base pressures changed to upper flap pressures, upper flap stop at 13°, eng thrust level reduced, engine thrust line changed from 3.75° to 1°50" nose up.
X-22-27	Circuit breaker add to alpha indicator circuit.
X-23-28	Nose camera installed, upper flap function of Mach n. modified, pilot's O_2 selector valve modified.
X-24-29	SAS roll & yaw boxes modified to accept AV feedback modification.
X-25-30	AV feedback installed but inactive, rudder bias stop changed from zero to 2° toe out, alternate attitude indicator installed.
X-26-32	Tufts removed, center fin camera pointed at engine, AV feedback active
X-27-33	Removed dynamic instrumentation, radar altimeter, nose camera, old battery cables, weight & balance
X-28-34	AV feedback gain increased, removed engine S/N 3, installed engine S/N 11, installed spare Mach sensor

X-24A FLIGHT OPERATION ATTEMPT SUMMARY

Date	Operation
1969	
2 Apr	B-52/X-24A Taxi test
4 Apr	X-1C-1 Captive flight
17 Apr	X-1-2
6 May	Cancelled due to weather (clouds)
7 May	Cancelled due to weather (couds)
8 May	X-2-3
8 Aug	X-A-4 SAS warning light problem and PCM ground monitor problem
21 Aug	X-3-5
29 Aug	X-A-6 Abort due to SAS PCM problem
9 Sept	X-4-7
24 Sep	X-5-8
10 Oct	X-24A Radio delay, cancelled due to weather (winds)
15 Oct	X-A-9 Abort due to weather (clouds)
21 Oct	Cancelled due to weather (rain)
22 Oct	X-6-10
13 Nov	X-7-11 (Communication delay)
25 Nov	X-8-12 (Delay due to α indicator problems)
1970	
20 Feb	X-2C-13 Captive flight
20 Feb	X-A-13 Abort due to SAS instrumentation problem
24 Feb	X-9-14 Delayed for weather
19 Mar	X-10-15
1 Apr	Cancelled due to weather (winds)
2 Apr	X-11-16
21 Apr	Cancelled due to weather (winds)
22 Apr	X-12-17
12 May	Instrumentation delay, cancelled due to weather (winds)
13 May	Cancelled due to weather (winds)
14 May	X-13-18
16 June	Cancelled due to SAS circuit breaker problems
17 Jun	X-14-19
28 Jul	X-15-20
11 Aug	X-16-21
26 Aug	X-17-22
13 Oct	Cancelled ground accident (hole punched in vehicle)

1970	
14 Oct	X-18-23
26 Oct	Cancelled due to weather (winds)
27 Oct	X-19-24
20 Nov	X-20-25 B-52/fire truck delay
1971	
20 Jan	Cancelled due to noisy α & β instrumentation
21 Jan	X-21-26
4 Feb	X-22-27
18 Feb	X-23-28
4 Mar	Cancelled due to weather (wind)
5 Mar	Cancelled due to weather (wind)
8 Mar	X-24-29
26 Mar	Instrumentation delay, cancelled due to weather (wind)
29 Mar	X-25-30
16 Apr	Cancelled due to weather (wind)
20 Apr	Cancelled due to weather (wind)
22 Apr	X-A-31 Abort due to weather (winds)
23 Apr	Cancelled due to weather (winds)
12 May	X-26-32
25 May	X-27-33
4 June	X-28-34

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Flight Test Center Edwards AFB, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE
Flight Planning and Conduct of the X-24A Lifting Body Flight Test Program

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final

5. AUTHOR(S) (First name, middle initial, last name)
Johnny G. Armstrong

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1972	109	16

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. AFFTC Project Directive 69-38 d.	9a. ORIGINATOR'S REPORT NUMBER(S) FTC-TD-71-10 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A

10. DISTRIBUTION STATEMENT Distribution limited to U.S. Government agencies only (test and evaluation), May 1972. Other requests for this document must be referred to ASD (SDQR), Wright-Patterson AFB, Ohio 45433.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	6510 Test Wing Edwards AFB, California

13. ABSTRACT

The objective to obtain piloted-low-speed flight test data on the SV-5 re-entry configuration was accomplished by the X-24A in 28 flights over a 27-month time period. Sufficient data were obtained to allow detailed reporting in the areas of handling qualities, performance, stability derivatives, flight loads, flight control system, unpowered landings, vehicle system operation, and mass characteristics. Extensive use was made of a six-degree of freedom simulator and between-flight determination of stability derivatives in expanding the envelope incrementally to 1.6 Mach number. Unexpected and significant reductions in directional stability were experienced with the rocket engine on. Handling quality problems encountered during the flight test program were improved by minor alterations of the control system. The variability designed into the control system contributed significantly to the research program by providing different aerodynamic configurations for data analysis and in allowing improvements in flight characteristics.

DD FORM 1 NOV 65 1473

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Security Classification

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
X-24A Lifting Body flight planning flight test conduct of program rocket engine power six-degree of freedom simulator						

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Ground Rules for No Launch

Ground rules for "no launch" were listed in each flight plan; a sample list is shown below:

1. Radio, radar; TM failure
2. Loss of individual TM parameters which were mission critical
3. Airspeed or altimeter failure
4. Angle of attack malfunction
5. Electrical or SAS malfunction
6. Any control system malfunction
7. Any landing rocket malfunction
8. Loss of cabin pressure
9. Any excessive canopy fogging
10. Overcast or poor visibility
11. Turbulence below 10,000 feet in excess of light
12. Maximum surface winds 10 knots, maximum crosswind 5 knots

After the first two flights indicated a possible problem with the flying qualities during final approach, the ground rule for turbulence was changed to "No turbulence allowed" for flights 3 and 4. The intent was to eliminate any external disturbing forces so the pilot could better evaluate the basic aircraft characteristics. To help achieve this, pre-flight turbulence checks were made in a light aircraft in the area the X-24 would be flying on final approach. In addition, in order to minimize the existence of turbulence, flights 3 and 4 were flown earlier in the morning (by 0715 hours). One problem that existed throughout the glide program even after the turbulence restriction was relaxed was the definition of the turbulence level. The absence of a "yard stick" with which to measure the turbulence level resulted in pilot "seat of the pants" opinion as regard to the turbulence level. As a result of control system improvement and increased pilot confidence through experience, the surface wind limit was increased above that shown in the Ground Rules for No Launch after flight 6 to a maximum of 15 knots and a crosswind of 10 knots.

Ground Control

The key functions of the ground control during an X-24A operation were to participate in the prelaunch checkout of the vehicle and to monitor the actual flight to provide the pilot with information to assist him in the successful and safe accomplishment of the mission.

In a central "control room", about 15 to 20 specialists monitored selected parameters directly associated with the real time conduct of the flight. Twenty-four PCM parameters were monitored on strip chart recorders while about 50 parameters were presented on meters. An addi-

tional 48 parameters were recorded and monitored on strip chart recorders in a room next to the control room, with a communication link between designated personnel in each room. A typical list of PCM parameters monitored is included in appendix I. Space positioning data on the NB-52/X-24A and the X-24A after launch were presented on radar plotting boards. Communication between the X-24A pilot and the control room personnel was only through the "ground controller", who was also a lifting body pilot. The controller was also responsible for coordinating all the various support activities associated with the flight such as chase aircraft, rescue helicopter, ground vehicles, etc.

During prelaunch operations, the personnel in the control room were responsible for verifying that all the established requirements for launch were met. Lack of verification resulted in the flight being aborted. It was not unusual for apparent problems to be satisfactorily solved or explained by the control room specialist during the countdown, thereby allowing the flight to proceed to a successful conclusion. The piloting task of the X-24A flights dictated that the pilot fly on instruments essentially from launch to low key, so he depended heavily on ground control for monitoring the performance of the vehicle systems and for energy management advisories. During the flight, the controller monitored the flight on the radar plotting board map. This map presented the planned downrange versus crossrange (track) and altitude versus downrange (profile) as established with the simulator. Deviations from the planned profile or track were radioed to the pilot along with reminder calls for preplanned key events.

FLIGHT PLANNING AND CONDUCT OF GLIDE FLIGHTS

General

Nine glide flights were flown prior to committing the vehicle to powered flight. One additional glide flight was flown later during the powered flight phase as a checkout for a new project pilot without previous lifting body experience.

One of the main goals of the glide flight program was to obtain basic aerodynamic data on the vehicle while expanding the envelope (Mach number, angle of attack, dynamic pressure) as much as possible. Hopefully, a high enough Mach number could be reached during glide so that the Mach number to be experienced on the first powered flight would be a reasonably small step. During the initial glide flights, considerable attention was required to develop satisfactory flying qualities during the approach and landing.

Three basic maneuvers were performed during flight to obtain aerodynamic data: pushover-pullup, pitch pulse, and lateral-directional doublet set. The pushover-pullup maneuver normally consisted of an angle of attack change from trim, down to two degrees, up to 17 degrees, and back to trim α in approximately 10 seconds. Longitudinal trim curves (α versus flap position) were obtained from each maneuver. Lift and drag data were also calculated from the angle of attack and measured body axis

accelerations. Longitudinal derivatives were obtained from pitch pulses with the pitch damper at zero gain. Lateral-directional maneuvers were accomplished as doublets (equal control input in each direction in order to minimize bank angle changes that would require unwanted pilot control inputs during the data maneuver). The maneuver that provided the best results was a rudder doublet followed by a short period of free oscillation and ending with an aileron doublet. These maneuvers were performed with roll and yaw SAS on when maneuver time was critical or when regions of expected poor flying qualities were being explored. Detailed discussions of the data maneuvers are included in references 4 and 6.

Conduct of First Flight

First Flight Considerations

The first flight of an air-launched lifting body vehicle is unique, in that the pilot has approximately two minutes to evaluate the actual flight characteristics and satisfy himself that no serious deficiencies exist that would compromise a safe landing. In addition adequate maneuvers must be performed to allow determination of performance (L/D) and longitudinal trim to compare with wind tunnel predictions so that the second flight can be approached with a higher degree of confidence. The first X-24A flight was planned to fulfill the above objectives.

First Flight Control Law

The design automatic control law contained several features that were considered unsuitable for a first flight. This control law, automatically changed the upper flap bias and rudder bias as a function of Mach number. A more simple control law consisting of fixed upper flap bias of -21 degrees and -10 degrees rudder bias was chosen for the first flight. This control law allowed a representative practice flare at high altitude, avoided switching from the lower flaps to the upper flaps, and made minimum use of automatic features. Both control laws are shown in figure 22.

The practice flare at high altitude allowed the pilot to become familiar with the flare capability and the handling qualities during the high speed preflare approach. At 33,000 feet the pilot was to push over to low angle of attack (2 degrees) and allow the vehicle to accelerate to 300 KIAS. At 25,000 feet, a 2-g flare was to be performed. One of the significant differences between the practice flare and final flare was the effect of altitude on Mach number for the same preflare airspeed of 300 KIAS. The practice flare Mach number was to be 0.7 compared to 0.5 for the final flare. This Mach number difference would have resulted in significant differences between the practice flare and final flare with the design control law. Note in figure 22 that the practice flare would have been flown totally on the lower flaps; while in performing the final flare, a transfer from the lower flaps to the upper flaps would have occurred. Obviously the final approach was not the place to begin to fly for the first time with a different set of control surfaces with different predicted control effectiveness.

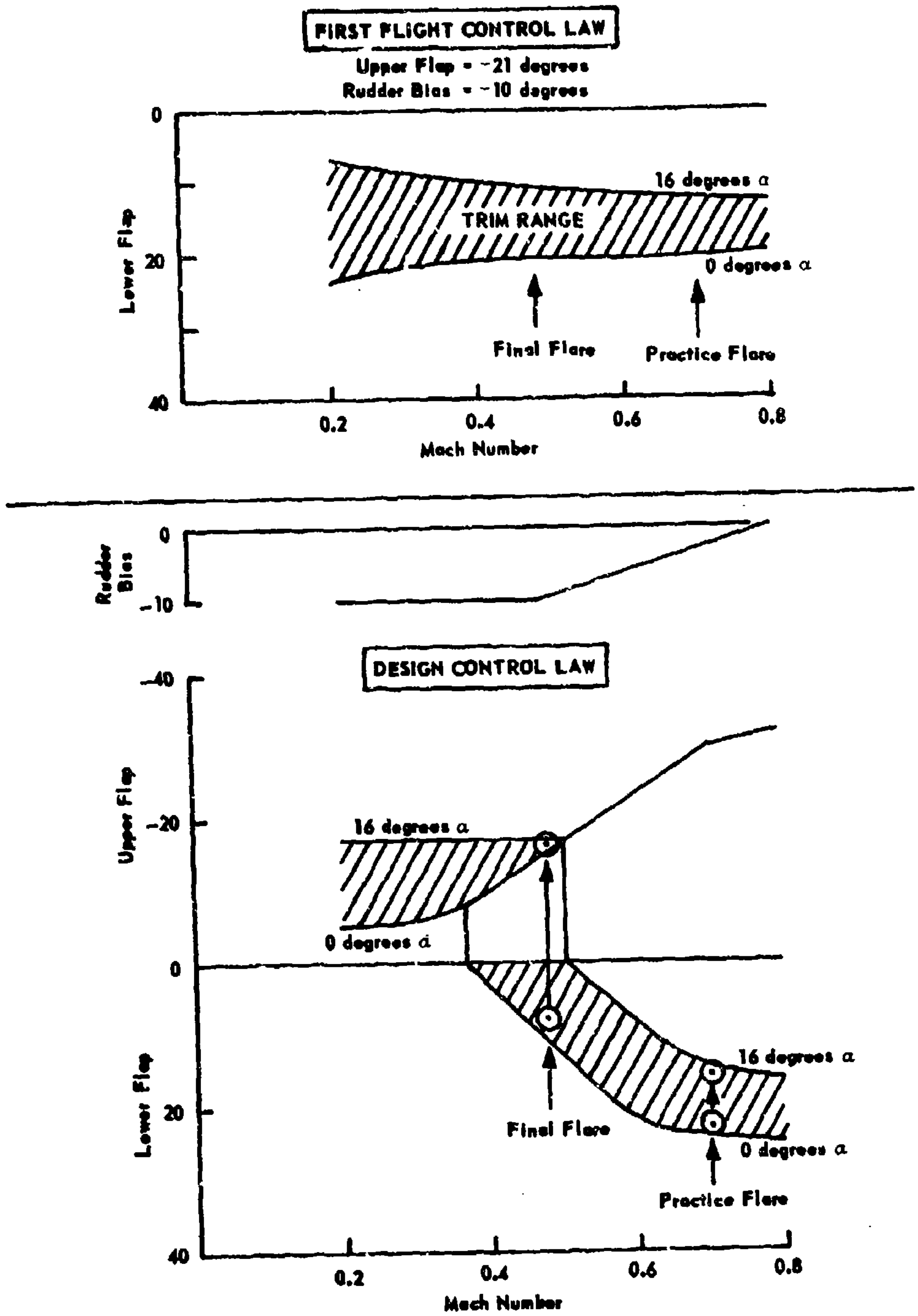


Figure 22 X-24A Control Laws

The Mach sensing system which would have driven the upper flap bias and rudder bias for the design control law was not completely redundant and therefore not a desirable mode of operation for a first flight.

The upper flap bias setting of -21 degrees and -10 degrees rudder bias chosen for the first flight was based on a compromise between desired maximum L/D, predicted stability margins at 0.7 Mach number and longitudinal trim to avoid cross over from the lower to the upper flaps. To achieve this desired longitudinal trim range the cg was moved aft to 58.5 percent by adding 140 pounds of ballast in the rear of the vehicle.

First Flight Events

The launch transient on the first flight was considered mild by the pilot with a maximum bank angle of 12 degrees. The lower flap setting had been chosen, based on wind tunnel data, to allow the aircraft to trim at eight degrees α after the launch transient. The trim was very close to predicted and the desired eight degrees α was acquired with very little pilot effort. However, the pilot noted a lateral misstrim and retrimmed the rudders until the aileron stick force returned to zero. This procedure of trimming out lateral asymmetry with the rudders rather than the ailerons had been established on the simulator as the best method because of the relatively high effectiveness of the rudders to produce a rolling moment through dihedral effect (C_{ℓ_β}) compared to differential deflection of the lower flaps. Nineteen seconds after launch, the pilot responded to a ground control request to reset the yaw SAS. One channel of the yaw SAS had failed at launch, lighting an amber light in the cockpit and in the control room. The pilot had not observed the warning light up to that time. This was a single channel failure in the yaw axis, and since each axis had two working channels the aircraft still had yaw damping.

In performing an evaluation of the roll control to ± 30 degrees of bank angle, the pilot found the vehicle to be more sensitive than he had expected from the simulation. In addition he noted a disconcerting characteristic of the vehicle to change lateral trim with changes in angle of attack.

The only automatic feature of the control system used during the flight was the scheduling of KRA with indicated angle of attack and this system malfunctioned. One minute after launch the KRA circuit breaker popped, disabling the automatic scheduling, thus locking the KRA at 35 percent for the remainder of the flight. This malfunction caused the master caution light to illuminate. The pilot observed the light, but was unable to devote enough attention to determine the cause of the master caution light illumination. The master caution light was a central repeater for several other warning lights at other locations in the cockpit.

At 33,000 feet the pilot pushed over to low angle of attack to accelerate for the practice flare. The pilot felt the vehicle was "real solid" at low angle of attack; however, only 260 KCAS was achieved for the practice flare. However, during the actual approach at 2 degrees α at approximately 300 knots the pilot experienced an uncomfortable lateral directional "nibbling". The sensation was similar to a characteristic he had experienced in the M2-F2 lifting body that was a symptom of a rather severe lateral-direction pilot-induced oscillation (PIO) tendency with large bank angle excursions. The pilot responded at approximately 1,800

feet AGL by increasing α to 4 to 5 degrees, allowing the airspeed to decrease to 270 KCAS, and using the landing rockets. At 240 KCAS, after completing the flare, the pilot deployed the landing gear and recovered from the predicted large nosedown trim change. Touchdown occurred at 194 KCAS, 8.3 seconds after gear deployment. Just prior to touchdown the lower flaps were rate limited because the maximum surface rate capability was insufficient to follow the large commands of the SAS and the pilot which were in phase. The longitudinal control during the flare was considered good.

Glide Flight Results

Launch Characteristics

X-24A motions while separating from the NB-52 after launch were found to be relatively small and the pilots generally described the transient as "mild." The magnitude of the transient motions that were experienced on flight 1, which were typical, may be seen in figure 23. The transient was generally damped out four seconds after launch. Prior to launching in a new aerodynamic configuration on successive flights, free flight longitudinal trim data were obtained with the new configuration on a preceding flight. This data allowed selection of a setting for the lower flap for launch to give the desired longitudinal trim based on actual rather than predicted pitching moment data.

Simulation studies of the launch characteristics were performed prior to the flight program without pilot inputs. A time history of the predicted motions for the first flight is included in figure 23. Generally, the simulation predicted much larger roll excursions than were ever experienced. The data for this simulation included data from wind tunnel force tests of 2 1/2 percent X-24A model in the presence of a B-52 model.

Separation clearance was qualitatively evaluated after each flight from high speed motion pictures taken from the pylon. Adequate clearance was observed on all flights.

	FLT. 1	SIMULATOR
WEIGHT ~ LBS	6350	6000
CG ~ % MAC	58.2	58.5
UPPER FLAP BIAS ~ DEG	-21	-21
RUDDER BIAS ~ DEG.	-10	-10
LOWER FLAP ~ DEG	-18	-18
MACH NO	.66	.65
PILOT INPUTS	YES	NO

FIGURE 23. LAUNCH CHARACTERISTICS ~ LIGHT WEIGHT

Landing Approach Flight Characteristics

After the first flight, it was felt that the apparent poor handling qualities during final approach were primarily the result of the higher-than-planned aileron-to-rudder interconnect. However, the reoccurrence of the problem on the second flight with the KRA programming normally eliminated it as the sole cause of the problem. During the final approach on the second flight, the lower flaps became rate limited. The roll damper could not be fully effective during the periods of surface rate limiting. This allowed the vehicle's roll rate excursions to reach 20 degrees per second; however, bank angle excursions were only ±4 degrees.

Prior to flight 3, considerable simulator investigation was performed to define changes to the vehicle to improve the flying qualities on final approach. The changes made to the vehicle's control system included: modification of the lower flap control horns to approximately double the maximum surface rate; changed the KRA schedule with α_i; and increased the control stick force gradient and stick damping in roll. More effective SAS gain settings in roll and yaw were defined (refer to the Yaw Due to Aileron section). The vehicle's response to simulated low altitude turbulence was included in the studies. Although the pilot's natural response to the vehicle's motion in turbulence could not be adequately simulated in the fixed base simulator, the effect of turbulence was concluded to be a significant contributing factor to the problem.

Although considerable improvement was realized due to the above changes, the response of the vehicle in turbulence continued to be of concern. It was not until the pilot became convinced that the motions he was sensing were "riding qualities" problems aggravated by turbulence, rather than a serious handling qualities deficiency, that he began to ride through the disturbance with increased confidence. The increased surface rates of the lower flaps prevented any further rate limiting problems. A more detailed discussion of this subject may be found in reference 5.

Yaw Due to Aileron

One of the most significant findings of the glide flight program was a difference between the wind tunnel and flight determined yawing moment due to aileron of the lower flaps. The wind tunnel data predicted the yawing moment would be adverse (negative $C_{n_{\delta_a}}$) at 0.5 Mach number at angles of attack less than 12 degrees. However, analysis of flight data revealed the yawing moment to be proverse (positive $C_{n_{\delta_a}}$), see reference 6. This difference was a contributing factor in the handling qualities problem experienced during the initial flights. With the flight-determined derivative used to update the simulator, more suitable SAS gains and a KRA schedule were established.

Upper Flap Control Tests

Tests were performed beginning with flight 5 to evaluate the vehicle's control characteristics below 0.5 Mach number using the upper flaps for pitch and roll control rather than the lower flaps. Removal of 140 pounds of ballast from the rear of the vehicle allowed the cg to move forward by 1 percent and provided a longitudinal trim condition that allowed crossover onto the upper flaps at an intermediate upper flap bias

setting of -10 degrees. This intermediate upper flap bias setting was chosen as a safety feature so that a change back to lower flap control could be made rapidly if control using the upper flaps was unsatisfactory. The first test of upper flap control was performed above 20,000 feet prior to low key. The more forward cg also served to decrease the longitudinal control sensitivity which was predicted to be higher when controlling with the upper flaps. The tests were successful with control being as expected and control derivatives obtained from data maneuvers in agreement with wind tunnel predictions. No problem was encountered in flight during the crossover from the lower to the upper flaps.

Minus Thirteen Degrees Upper Flap Bias Approach

All landing approaches through flight 6 were performed at upper flap bias settings from -19 degrees to -23 degrees. On flight 7, a portion of the landing approach was performed at an upper flap bias setting of -13 degrees. The test was planned to verify expected satisfactory handling qualities at the lower wedge angle[2] to take advantage of increased glide performance. A final approach L/D increase from approximately 2.2 to 3.0 was realized with this smaller upper flap bias and thus a shallower approach angle by about 6 degrees. This test was successful, and on flight 8 the complete landing pattern was performed with -13 degrees upper flap bias. The landing approach was performed with this upper flap bias setting using the lower flaps for control. The longitudinal trim change due to landing gear deployment required sufficient aft stick to cause the lower flaps to fully close with a resulting crossover to the upper flaps for control. This rapid transfer of authority was considered desirable due to the large deadband associated with the crossover and was a consideration in the selection of -13 degrees upper flap bias. The landing itself was performed using the upper flaps. This configuration became the standard landing configuration except for two landings which were specifically planned to evaluate a complete landing approach using only the upper flaps for control. During these two landing approaches using the upper flaps for control, the handling qualities were as good as those obtained in the -13 degrees upper flap bias configuration and a performance increase was realized. However, since this configuration did not provide a speed brake capability, it was not adopted as a standard landing configuration (reference 1).

Flow Separation

Flow separation over the rudder surfaces was indicated on the first two glide flights in the rudder hinge moment and accelerometer data. It was noticeable to the pilot as a mild, high frequency, "Mach type" buffet. The onset of the buffet was observed to occur as low as 0.56 Mach number. It was felt that possible problems caused by the flow separation should be avoided on those flights while the landing approach flying qualities problem was being investigated. To minimize the occurrence and intensity of flow separation, the Mach number was intentionally kept below 0.6 during the next four flights by launching at 40,000 feet rather than 45,000 feet. During these flights, tufts on the tip fin, rudder, and upper and lower flaps were photographed from onboard and chase plane cameras to evaluate the flow fields (see appendix I for sample photos). These films showed that the flow separation occurred on the inside of the tip fin and

[2] Wedge angle is the total angle of the absolute upper flap angle plus the lower flap angle.

rudders. The correlation between the tuft photos and hinge moment data for the onset of separation was good. The boundary for onset of buffet from the flight corresponds quite well with a non-linearity in the wind tunnel derivative of C_{n_β} and C_{ℓ_β}. The effect of separation on the vehicle was more destablizing at low upper flap positions. References 3 and 4 treat this subiect in more detail.

Lateral Trim Change

The lateral trim change with changes in angle of attack continued to be an annoying flight characteristic to the pilots throughout flight 7. It was most noticeable while flying in the 0.5 to 0.7 Mach range with intermediate upper flap settings (-19 to -23 degrees). This lateral trim change was probably a result of asymmetrical tip fin flow separation. Extending the upper flap reduced the severity of the flow separation effects. As the upper flap settings were increased on later flights (-30, -35, and eventually -40 degrees), the lateral trim change with α decreased in magnitude. In addition between flights 8 and 9, a known warpage in the upper left hand flap was corrected to reduce known asymmetric conditions.

Transonic/Subsonic Configuration Change

The X-24A stability levels were a strong function of upper flap bias and to a somewhat lesser degree, rudder bias. Data were obtained over a range of upper flap bias positions of -10 to -35 degrees and rudder bias positions of -10 to 0 degrees during the glide flight program. Stability requirements dictated that increased upper flap bias be used as Mach number increased. The subsonic configuration developed for Mach numbers less than 0.5 was -13 degrees upper flap bias and -10 degrees (toe-in) rudder bias. Test results dictated that initial plans to use -30 degrees upper flap bias as the transonic configuration for the initial powered flights had to be changed to -35 degrees to achieve adequate stability margins.

Configuration changes of the upper flaps and rudder bias (through flight 8) were accomplished by the pilot as separate changes with two separate switches. Prior to flight 9, rudder bias programming was synchronized with the measured upper flap bias position in the automatic mode. This allowed the pilot to perform the configuration change as a single event in 10.3 seconds using the upper flap bias switch on top of the landing rocket throttle. This handle was a T-33 aircraft throttle handle with the switch normally used as the speed brake switch for that aircraft. One of the considerations for this modification was to provide the X-24A with a speed brake capability below 0.6 Mach number through modulation of the wedge angle and rudder bias.

The automatic scheduling of rudder bias with upper flap bias was linear between -33 degrees upper flap bias, 0 degrees rudder bias and -13 degrees upper flap bias, -10 degrees rudder bias. The noseup trim change resulting from rudder bias movement from 0 to -10 degrees partly compensated for the nosedown trim change caused by the upper flap bias in closing from -33 to -13 degrees. The result was a configuration change and speed brake deployment that were easy to perform with little longitudinal trim change.

Energy Management

The ground tracks used for all X-24A glide flights were basically as shown in figure 24. The launches, except for that of flight 3, occurred between points A and B along the south edge of Rogers Dry Lake. The flights proceeded along the east shoreline to the low key point. The pilot then performed a 180-degree pattern and a high speed (300 KCAS) final approach to a landing on Runway 18. Reference 1 analyzes the landing aspect of the program in detail.

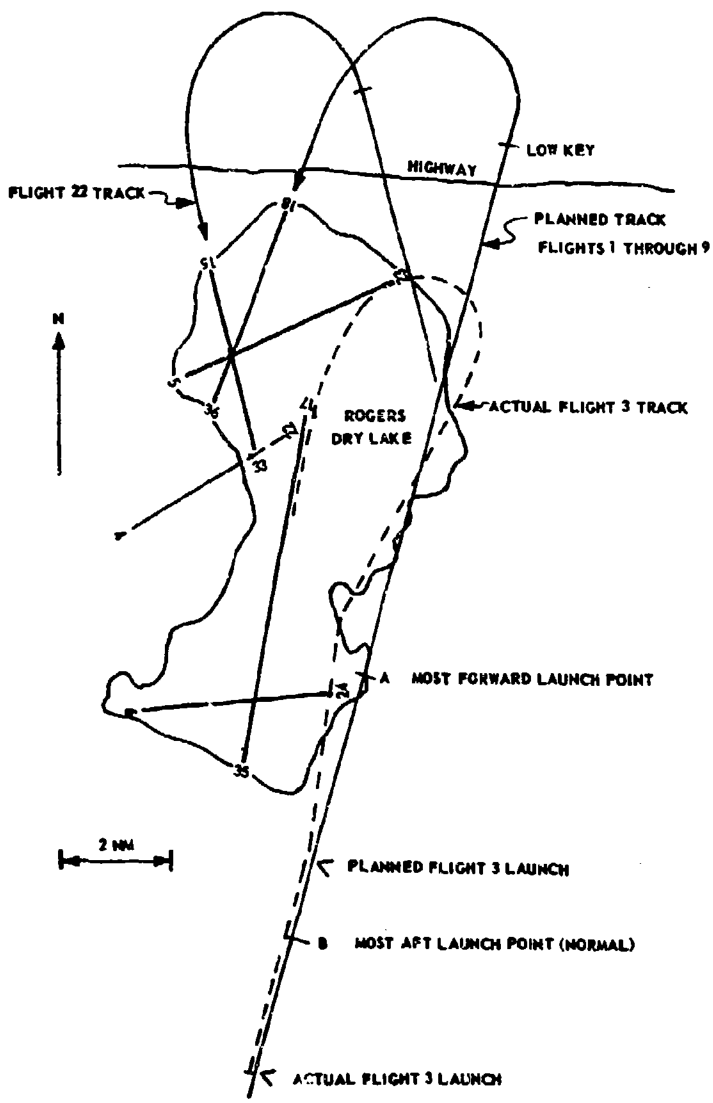


Figure 24 Glide Flight Ground Tracks

All planned data maneuvers, with very few exceptions, were accomplished prior to low key, to allow the pilot to devote his full attention to the landing. The exact geographic launch point for each flight was determined on the simulator depending on the launch altitude, aerodynamic configuration, and angle of attack schedule to be flown to arrive at low key between 18,000 and 20,000 feet. On the morning of the flight, winds at altitude as determined from a Rawinsonde balloon normally released at 0200 hours, were used to calculate the effect of wind on the ground track. Initially, the wind correction was hand calculated using "dead reckoning" procedures. Because of high rates of descent the vehicle never stabilized within any particular layer of moving air but rather traversed through changing air masses rather rapidly. Correctly predicting the resulting effect of wind and wind shear on the profile was found to be mathematically quite complex. Therefore, to be technically correct in accounting for the effect of winds on the planned profile, the simulator was programmed to correct for these effects using stored values of wind speed and direction as a function of altitude. The simulator was operated on the morning of the flight to determine the effect of winds on the profile. The launch point was shifted to allow the pilot to fly the planned mission and arrive at low key without major deviations. Launch point shifts of up to one nautical mile were used during the glide flight program. This refinement was an attempt to keep deviations to a minimum in order that all planned data maneuvers could be accomplished.

The data maneuvers required that the pilot be essentially "on instruments" until approaching low key. It was the controller's job to give the pilot adequate information so corrections could be made to reach the turn point at the proper altitude. The heading corrections were made by the pilots at appropriate times in between data maneuvers. In general, energy management was never a problem on the glide flights because the performance was close to predictions and small deviations from the planned energy were easily corrected. Two common methods of adjusting energy were: (1) angle of attack/airspeed variations (in between data maneuvers when possible) and (2) changing the time of the planned configuration change (low L/D to high L/D configuration).

The 180-degree turn to final approach proved to be a very satisfactory pattern for controlling energy to achieve the desired landing point. In most cases, the pilots were able to practice the glide flight on the morning of the X-24A flight in an F-104 aircraft. Most of their practice was devoted to the pattern from the turn point to touchdown. This allowed the pilot to become aware of the effects of the existing upper altitude winds on his planned pattern.

On the third flight, a procedural error in the NB-52 resulted in an inadvertent launch approximately 45 seconds early. All the vehicle systems were in a flight-ready status at that time. Although initially surprised, the pilot began to perform the planned data maneuvers while assessing his probable landing site. The controller observed that the actual launch point was off by 4 nautical miles, about the same distance from the planned landing runway 18 to Lakebed runway 17 (figure 24). The controller recommended runway 17 for landing and the X-24A pilot concurred. This timely decision allowed the pilot to fly his planned mission, obtain all the requested data maneuvers, and successfully recover the aircraft from an emergency situation. The actual track is shown in figure 24. After this flight, procedural and equipment changes were made to reduce the possibility of recurrence of this problem.

Glide Flight Envelope

The envelope of Mach number versus altitude plot for all glide flights is shown in figure 25 along with pertinent limits. The complete X-24A vehicle was not subjected to structural proof load testing although proof loads were applied to one of the tip fins. For this reason the flight test operational limit was restricted to 80 percent of the design limit. Application of the 80-percent restriction to the early design points resulted in dynamic pressure limits which were unduly restrictive in the 0.7 to 1.0 Mach region especially for the rotation phase of powered flights. The contractor reanalyzed the basic structure for the design points shown in figure 25 and found the design adequate. The operational limit then became 330 KCAS below 1.05 Mach. Above 1.05 Mach, the operational limit was 300 pounds per square foot dynamic pressure based on hinge moment requirements for single hydraulic system operation.

The value closest to the operational limit was attained during the high-speed final approach to landing. Another isolated instance in which the limit shown on the figure was nearly reached occurred during the high-speed approach to the practice flare at 26,000 feet on flight 1.

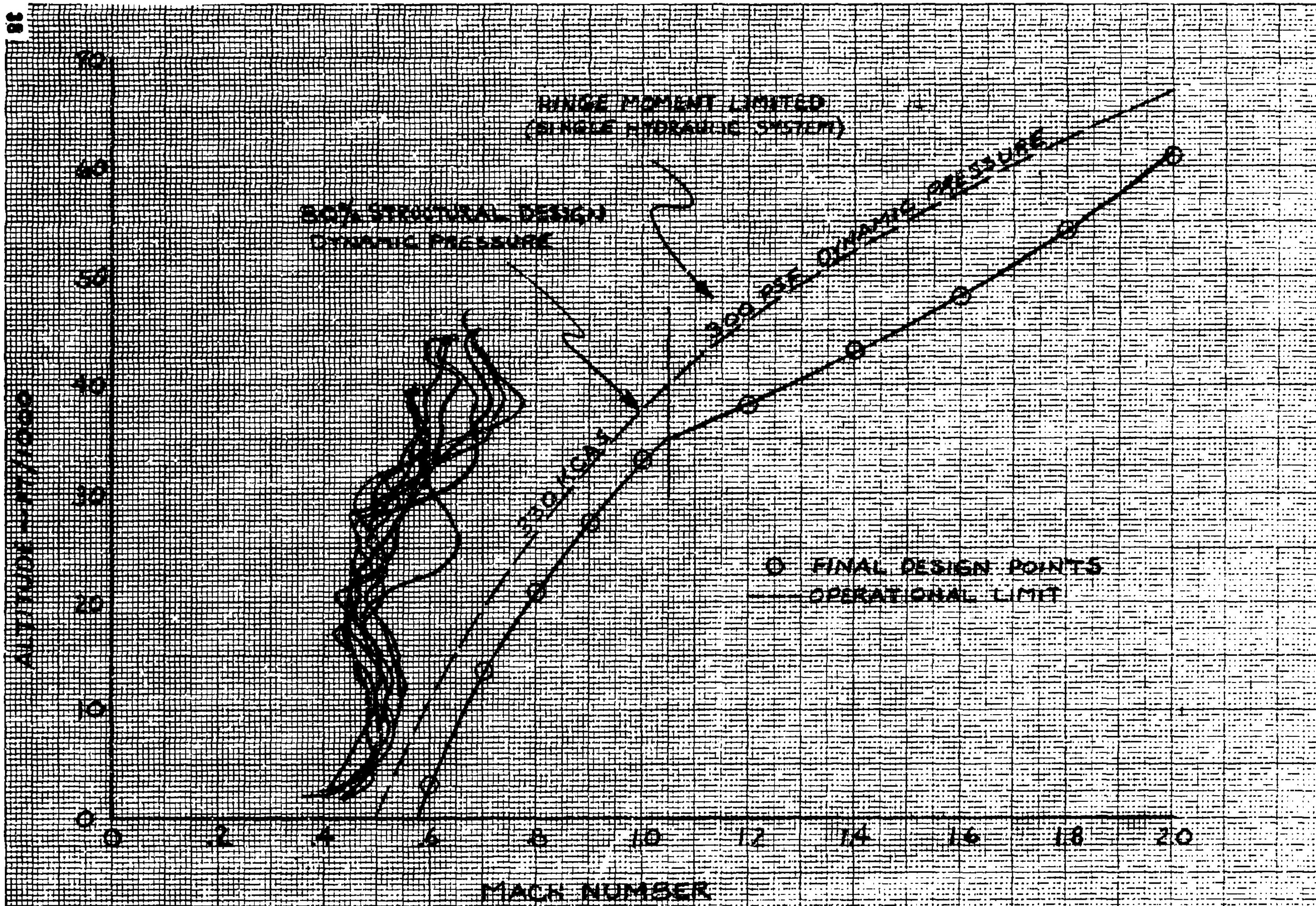


FIGURE 2.5. GLIDE FLIGHT SUMMARY

FLIGHT PLANNING AND CONDUCT OF POWERED FLIGHTS

General

Eighteen powered flights were flown during the flight program. A typical X-24A powered flight consisted of two and a half minutes of rocket-powered flight followed by a five-minute glide to landing. The Mach number envelope was expanded in small successive steps with interruptions to further investigate handling qualities problems on several occasions. Primary flight objectives were not accomplished on five flights in which system failures which occurred after launch resulted in alternate flights being flown.

Flight planning and crew preparation efforts were considerably increased over that required for a glide flight. In addition to the increased complexity of the basic powered flight plan, a large number of possible deviations from the normal had to be prepared for. Over 20 hours of simulator time were commonly utilized by the pilot in preparation for a flight. Inflight practice in the F-104 was also increased to include approaches to as many as five possible landing runways. It has been estimated that the pilots performed as many as 60 landing approaches during the 2-week period prior to their flight in the X-24A.

In general, the primary objective of each powered flight consisted of performing data maneuvers near the point of planned maximum Mach number for that flight. To achieve these desired end conditions, precise control of the profile was required. Therefore, data maneuvers during powered flight were generally limited to those angles of attack required for profile control. In order to prevent possible large upsetting maneuvers that could compromise the profile, all data maneuvers performed with power on were accomplished with the SAS engaged. The capability to individually operate the four chambers of the XLR-11 rocket engine allowed selection of a reduced thrust level upon reaching the desired test conditions to provide additional data time at quasi-steady flight conditions.

The powered portion of high performance flights of the rocket powered X-24A lifting body consisted of three distinct piloting phases: (1) rotation after launch at constant angle of attack, (2) climb at constant pitch attitude and (3) acceleration at low angle of attack to desired Mach number. Optimization of these three phases to determine the procedure for maximum performance was accomplished by simulator parametric studies. The problems associated with flight in each phase will be discussed later. In some cases new limiting factors or deficiencies were uncovered that required alteration to the procedure for maximum performance, usually with a resulting decrease in maximum Mach attainable.

Conduct of First Powered Flight

First Powered Flight Considerations

Prior to the end of the glide flight program, detailed flight planning for the first powered flight revealed that the rotation could not be performed at -30 degrees upper flap bias without encountering flight

conditions (M and α) where the wind tunnel predicted negative values of C_{n_β}. Figure 26 depicts the rather sizable step from flight experience (through flight 8) that would have occurred during a rotation from 45,000 feet with all 4 rocket chambers ignited and with the upper flap bias at -30 degrees.

Simulator studies indicated two of the most effective flight planning techniques to reduce the resulting Mach number and airspeed during the rotation were to lower the launch altitude and use fewer rocket chambers. The practical limit to this for the X-24A was established by simulator studies to be 40,000 feet and 2 chambers and would have resulted in the conditions shown, a significant decrease in peak Mach but C_{n_β} would still be negative. Also shown is the expected improvement in margins for a rotation with -35 degrees upper flap bias and 17 degrees indicated angle of attack (α_i). The increase in upper flap bias would have significantly increased the usable angle of attack at predicted values of positive C_{n_β} and peforming the rotation at 17 degrees α_i with 2 chambers from 40,000 feet would have reduced the expected maximum rotation Mach number to a reasonable value.

In order to obtain flight test data at the -35 degrees upper flap bias position, an additional glide flight (9) was performed. To expand the Mach/α flight experience to that shown in figure 26, the vehicle was launched from 47,000 feet and a low angle of attack maintained to achieve high Mach number prior to pull up to high α. Although the time at this condition was short, confidence was gained to proceed with the first powered flight in this configuration.

Vehicle Preparation

Preparation of the vehicle for powered flight included propulsion system ground tests, addition of two 79-amp-hour hydraulic pump batteries, and cockpit update for pressure suit flights.

Prior to the first captive flight with the fully serviced vehicle, the natural frequencies of the NB-52/pylon/X-24A combination were determined by ground tests to be satisfactory (3.2 Hertz in pitch and 3.0 Hertz in roll). Vehicle/pylon motion was studied during a high speed B-52 taxi test. During the captive flight the following items were checked:

1. Full serviced X-24A/adaptor damping
2. Pylon load measurements
3. The propulsion system prelaunch checks were made in the flight environment. This also included the propellant jettison system.
4. Verification of pressure suit operation (nonstandard overboard dump).
5. Verification of the completeness and timing of the prelaunch check list.

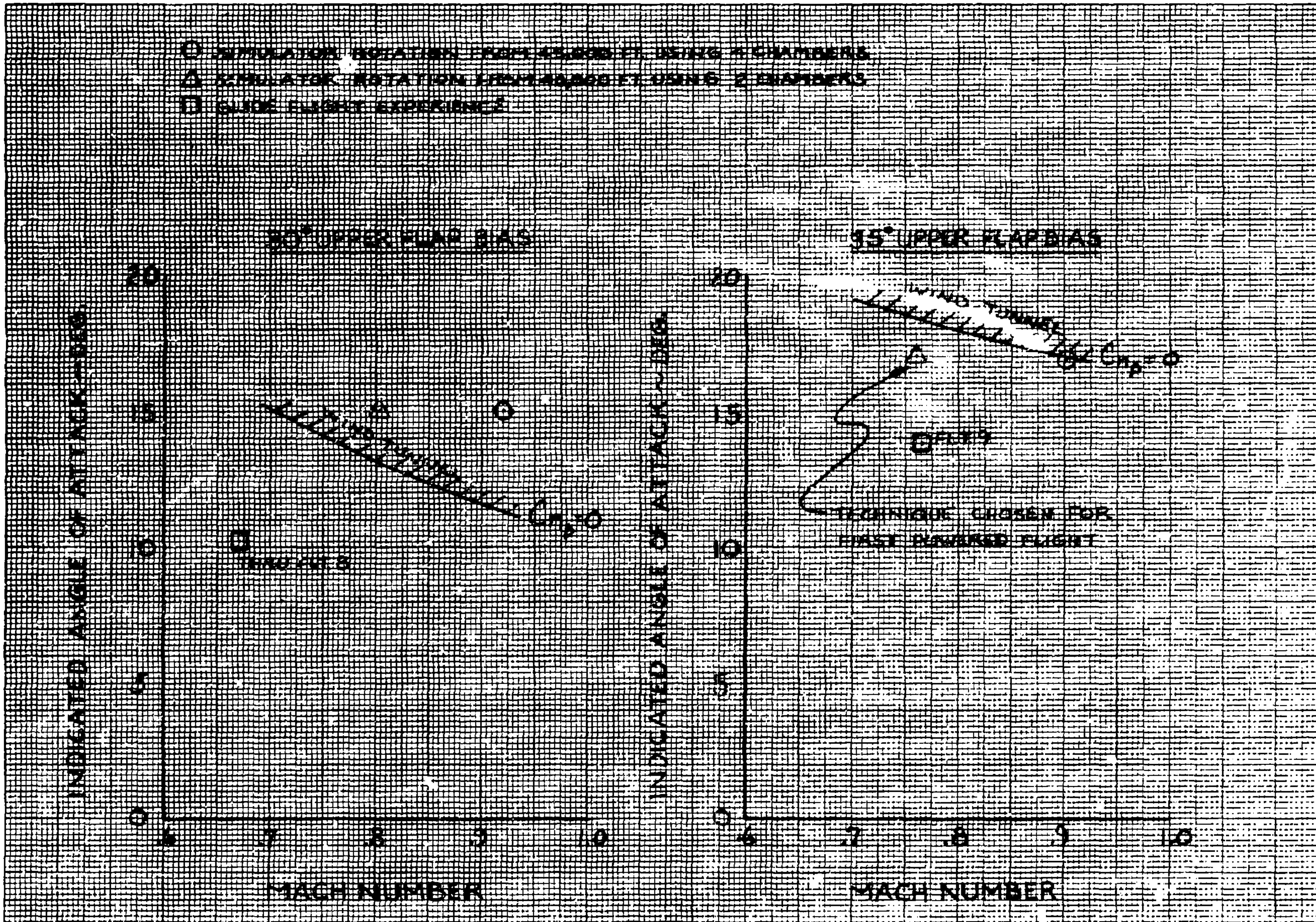


FIGURE 26. ROTATION FACTORS

First Powered Flight Events

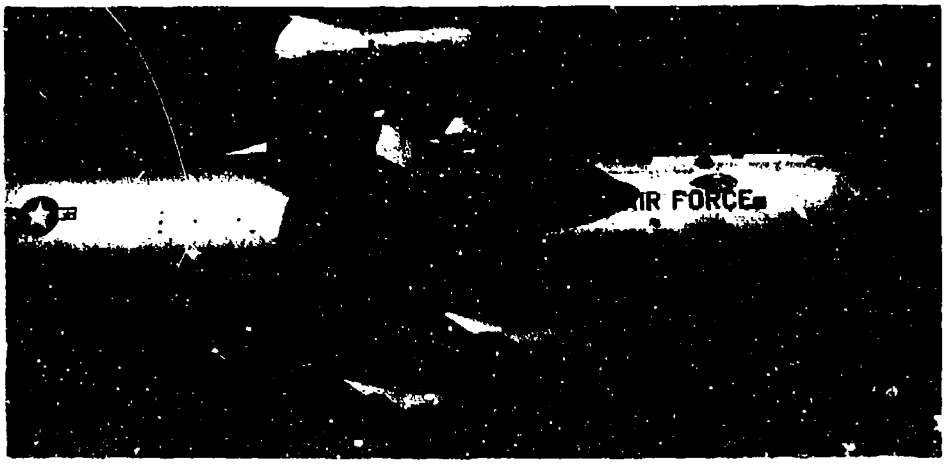
The main objectives of the first powered flight were to successfully accomplish the powered flight profile as established on the simulator and to perform lateral-directional maneuvers to obtain stability derivatives at Mach and α conditions near that to be experienced during rotations on future flights. The maximum Mach number during rotation was successfully limited to a low value (0.74) by launching at 40,000 feet and using only two rocket chambers. After the Mach number and airspeed reached a maximum during the rotation, a third chamber was ignited to provide the required thrust to climb and accelerate to the planned test conditions. Rudder and aileron doublets were performed at 0.80 to 0.84 Mach number at 11 to 13 degrees α_i. Stability and control derivatives extracted from these maneuvers after the flight were in general agreement with wind tunnel values. The value of Cn_β was slightly lower than expected, but still adequate. The pilot felt the vehicle's handling qualities were better than those demonstrated in the simulator. The simulation was intentionally based on the most pessimistic fairing of wind tunnel data where such a choice was possible. The vehicle exhibited better performance under power than had been predicted by the simulator.

The results of the first powered flight were quite satisfactory and without problems, so the second powered flight followed after a normal "turn around" of two weeks.

Powered Flight Results

Launch Characteristics with Propellants

The launch characteristics with the vehicle fully loaded with propellants for a powered flight was not significantly different from those of the launches experienced with the empty vehicle. A comparison of the motions of an empty vehicle launch (flight 22) and a fully loaded launch (flight 15) with similar upper flap bias and rudder bias settings is shown in figure 27. Separation clearance for all the powered flight launches was satisfactory.



	FLT. 15	FLT. 22
WEIGHT ~ LBS.	11,500	6320
C.G. ~ % MAC	55.7	57.7
UPPER FLAP BIAS ~ DEG	-3.5	-3.5
RUDDER BIAS ~ DEG	0	0
LOWER FLAP ~ DEG	2	24
MACH NO.	.65	.69
ALTITUDE ~ FT.	42,000	45,000
KCAS	135	175

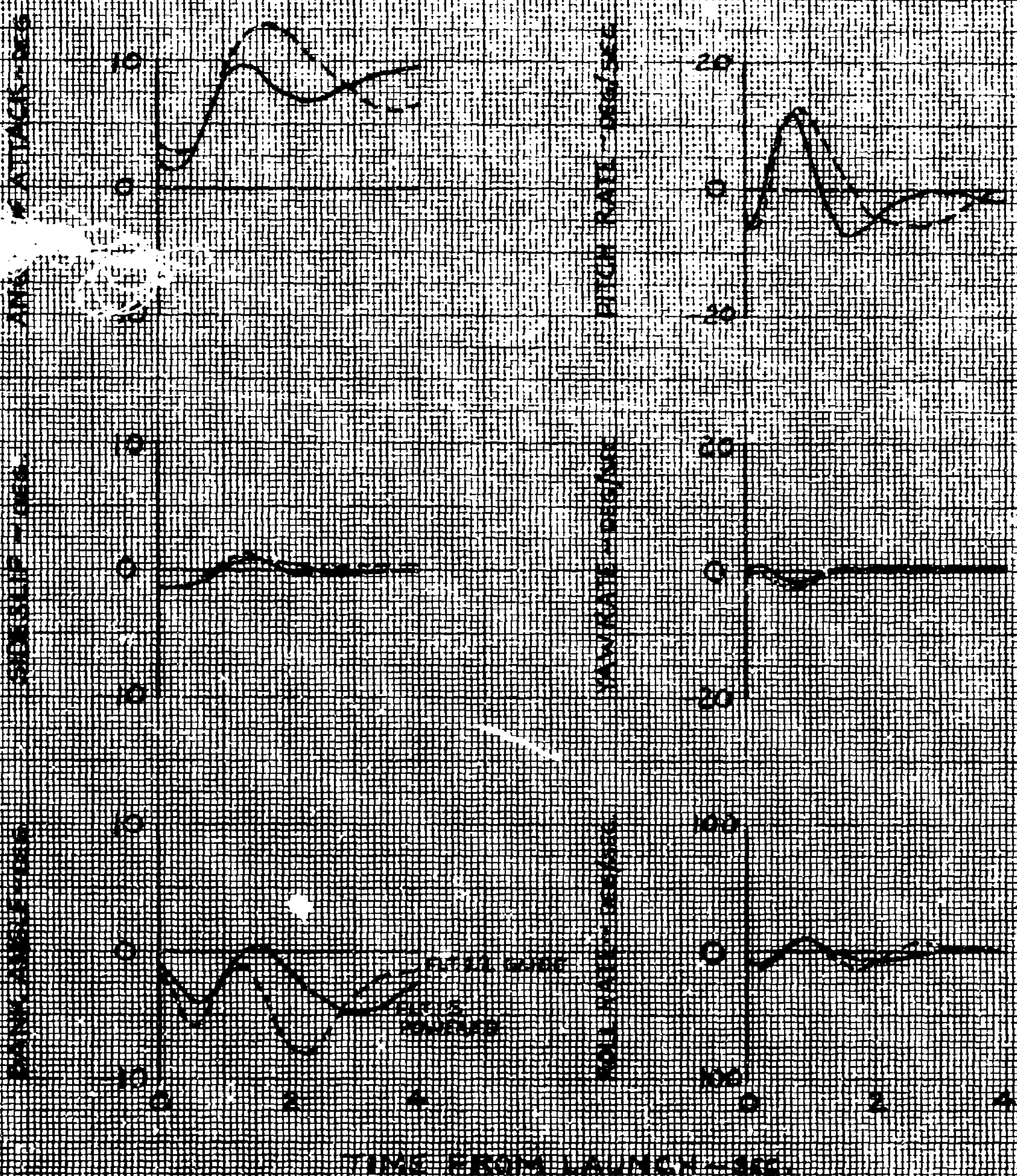


FIGURE 27. LAUNCH CHARACTERISTICS ~ HEAVY WEIGHT

Rotation Conditions

Flight conditions experienced during the flight program while performing the rotation are summarized in figure 28. Shown as a function of planned launch altitude are the maximum Mach number, airspeed, and altitude loss during the rotation. It can be seen that a buildup approach in rotation Mach and airspeed was possible on the first three flights (10, 11, and 12) because the XLR-11 engines could be operated with individual thrust chambers. This feature was also utilized on flight 24 to allow a more conservative flight plan to be flown for a new lifting body pilot on a powered checkout flight. An expected decrease in maximum Mach and airspeed resulting from increased drag associated with an upper flap bias change from -35 to -40 degrees can be noted by comparing flights 14 and 15 with flight 18. The variation of maximum rotation Mach number with launch altitude may be seen for both upper flap configurations when compared with the variation established on the simulator. The amount of scatter was not surprising because of the significant effect of piloting technique and atmospheric conditions (wind and temperature) on these parameters. The most sensitive parameter was the angle of attack maintained during the rotation. The planned indicated angle of attack for all the maximum Mach number points shown was 17 degrees. The average angle of attack for most of the flights was within ± 2 degrees of the target value. The average angle of attack for flight 21 was 4 degrees higher than planned because of an α indicator malfunction. As can be seen this resulted in the lowest altitude loss of any flight. The time required to achieve successful operation of all four chambers was a factor in the scatter of the data shown. Figure 29 shows the time after launch for the pilot to obtain thrust from each rocket chamber. The time shown in figure 29 was when the longitudinal acceleration showed a significant increase. An additional time increment of approximately three quarters of a second was required to reach a stabilized level of acceleration corresponding to 100 percent thrust. The normal procedure was to light two opposing chambers at a time (i.e., 1 and 3 or 2 and 4, figure 29). The first two chambers were lit immediately after launch, the second pair was lit after the first two chambers reached a chamber pressure of 155 psig as indicated by illumination of the chamber lights in the cockpit. All flights shown were intended to be with 4 chambers ignited except 10, 11, and 24. Note that the average time for thrust onset for the first two chambers was three seconds and six seconds for the other pair. Time delays longer than 10 seconds shown in the figure were the result of engine malfunctions.

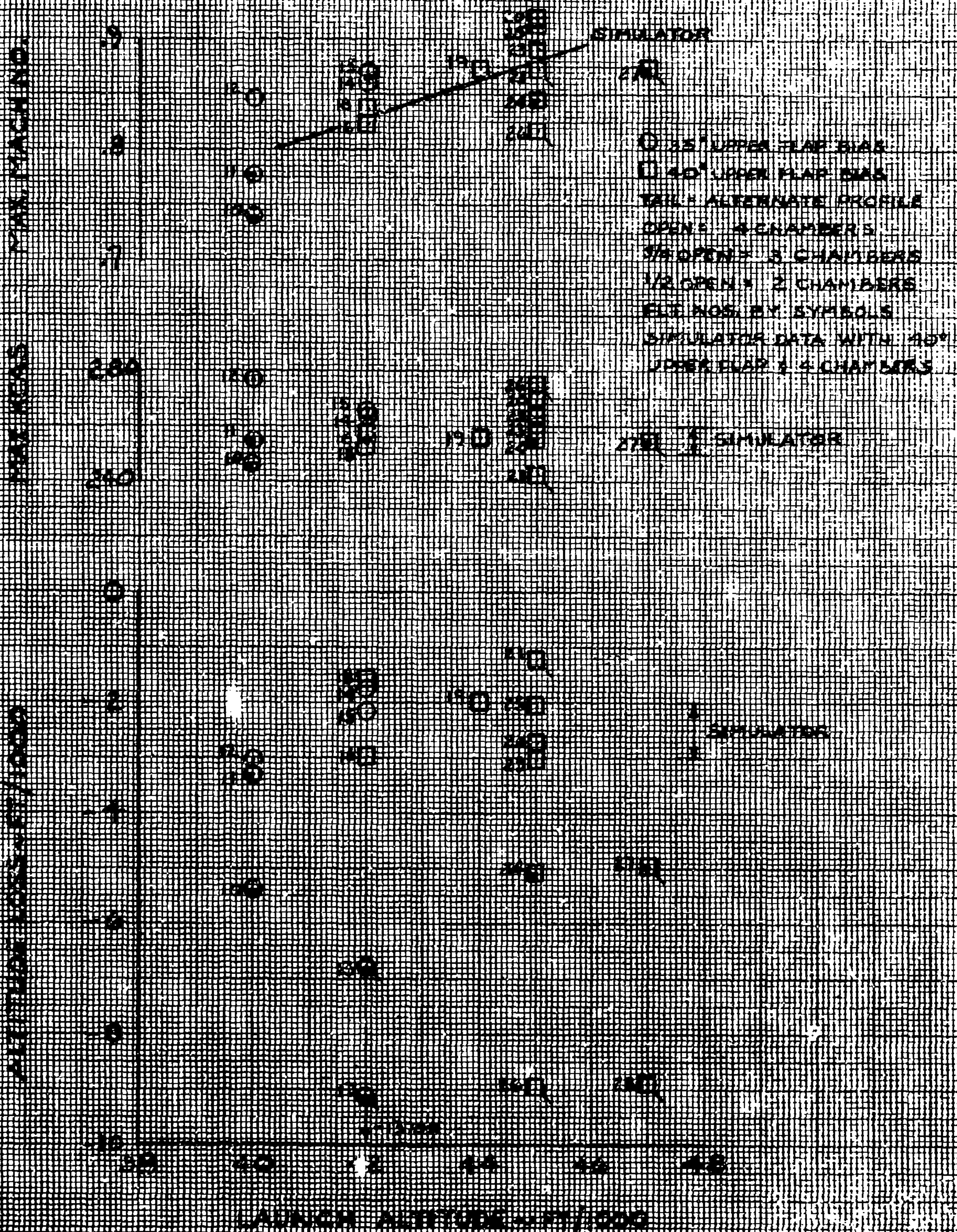
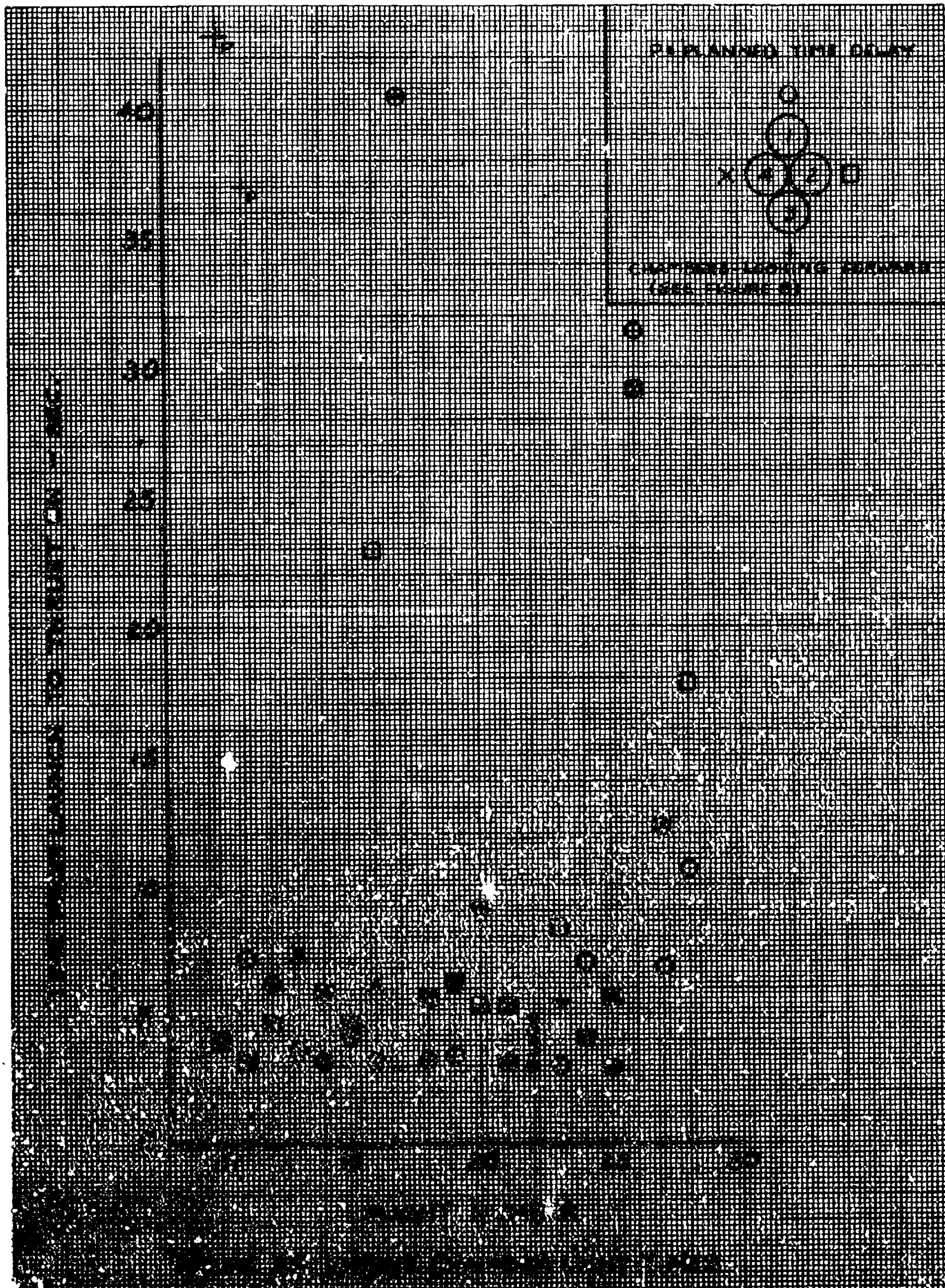


FIGURE 29. TEST ROTATION CONDITIONS



PLANNED TIME DELAY
1
2
3
4
40
35
30
25

Transonic Handling Qualities

The first five powered flights (10 to 14) were flown with the upper flap bias at -35 degrees. Maximum Mach number obtained to that point was 0.99. On flight 14 the pilot encountered an area of poor roll control at 0.95 Mach number at 5 degrees α_i and rated the lateral-directional handling qualities[3] as 6.5. Also by this time adequate flight data had been obtained to define a trend that C_{n_β} was less than wind tunnel predictions. As a result of these two factors a comprehensive review was performed to assess the implications on future envelope expansion flights. A simulator study was made using the flight determined values of C_{n_β} resulting in handling characteristics similar to those encountered in flight. Control system changes or adjustments which would improve handling qualities were evaluated on the simulator. Increased KRA and an increase in yaw gain were defined as the most effective changes to improve the handling qualities problem. A wind-tunnel-predicted increase in C_{n_β} between -35 and -40 degrees upper flap bias was considered an attractive change. Therefore, -40 degrees upper flap bias was used as the transonic/supersonic configuration for the remainder of the flight program. Detailed analysis of all the available data after the flight program failed to verify any significant increase in C_{n_β} between -35 and -40 degrees upper flap bias (reference 6); however, it should be noted that no data were obtained with -35 degrees upper flap bias at $M > 1.0$. With respect to the particular handling qualities problem discussed, the changes made did result in an improved pilot rating of 3.0 in the 0.95 Mach region at low α.

Stability Boundaries

Two successful data flights (15 and 16) in the -40 degrees upper flap bias configuration produced adequate data to indicate that the C_{n_β} was still lower than predicted. These flight data when faired in with wind tunnel data at supersonic speeds and extrapolations to higher α's based on the slope of the wind tunnel data were used as the basis for studies that established flight boundaries. Figure 30 presents the resulting boundaries which were used as a guide for flight planning. Two regions of roll reversal were defined. The low angle of attack condition had already been approached and its existence verified. This low α limit, in combination with the α for $C_{n_\beta} = 0$ and the upper roll reversal boundary, resulted in a rather limited usable α corridor in the transonic Mach range. Flight in the region of negative C_{n_β} was necessary to reach desired flight conditions, however, flight in this area was approached with caution with alternate pilot action already preplanned if a control problem was encountered. The angle of attack for zero $C_{n_\beta}^*$ was considered an absolute limit and was never penetrated. Negative values of $C_{n_\beta}^*$ produce a condition for which lateral-directional motions are non-oscillatory and divergent. ($C_{n_\beta}^*$ or C_{n_β} dynamic defined by $C_{n_\beta}^* = C_{n_\beta} \cos \alpha - \frac{I_z}{I_x} C_{\ell_\beta} \sin \alpha$). Always of consideration was the lack of longitudinal static stability (C_{m_α}) predicted by wind tunnel data at high angles of attack

[3] Handling qualities ratings in this report are based on the Cooper-Harper scale of reference 16 included in appendix III.

between 0.70 and 0.90 Mach number and at low α at 0.95 Mach number. In preference to the above factors, an indicated angle of attack of 17 degrees was normally used to perform the rotation.

Adherence to these boundaries did not seriously restrict the glide portion of the flights after engine shutdown. However, performing an optimum boost profile to achieve maximum performance was compromised because of the inability to rotate efficiently and climb at a steep pitch angle and the inability to push over to near zero lift for the acceleration to maximum Mach number. Included on figure 30 is a typical X-24A simulated high speed flight. Note that the rotation was performed in an area of negative C_{n_β} (based on extrapolated data). Test values of C_{n_β} at this Mach and α were not obtained because of the reluctance to perform an upsetting data maneuver during the rotation. Also apparent is that the rotation was performed close to roll reversal and $C_{m_\alpha} = 0$. Pilot comments indicated that the lateral-directional handling qualities during the rotation were always acceptable. During the constant pitch angle (θ) climb the vehicle once again reached the area of negative C_{n_β}. However, this time the airspeed was low (150 knots), and the pilots encountered a lateral-directional PIO with pilot ratings as high as 7.0. To avoid deeper penetration into this boundary, it was necessary to push over to lower α prior to accelerating above 0.9 Mach number. The limiting pitch angle during the boost of approximately 40 degrees was dictated by the indicated angle of attack limit of 17 degrees. The limitations of 40 degrees pitch angle and 0.9 Mach at pushover resulted in a pushover altitude and rate of climb lower than optimum and precluded the capability to maintain a low angle of attack for the remainder of the acceleration (a technique which normally would result in maximum performance). If attempted, the vehicle would have leveled off at too low an altitude and accelerated to a high dynamic pressure and a very steep dive angle at engine burnout. To preclude this, it was necessary to perform a two-step pushover. As shown in figure 30, the first pushover was to 10 degrees α_i for acceleration to $M > 1$ and to gain additional altitude. At 1.2 Mach number a pushover to 7 degrees α_i was performed for the final acceleration to maximum Mach number. A time history of actual performance parameters resulting from one of the buildup flights (flight 23) is shown in figure 31. The Flight Plan may be found in appendix IV.

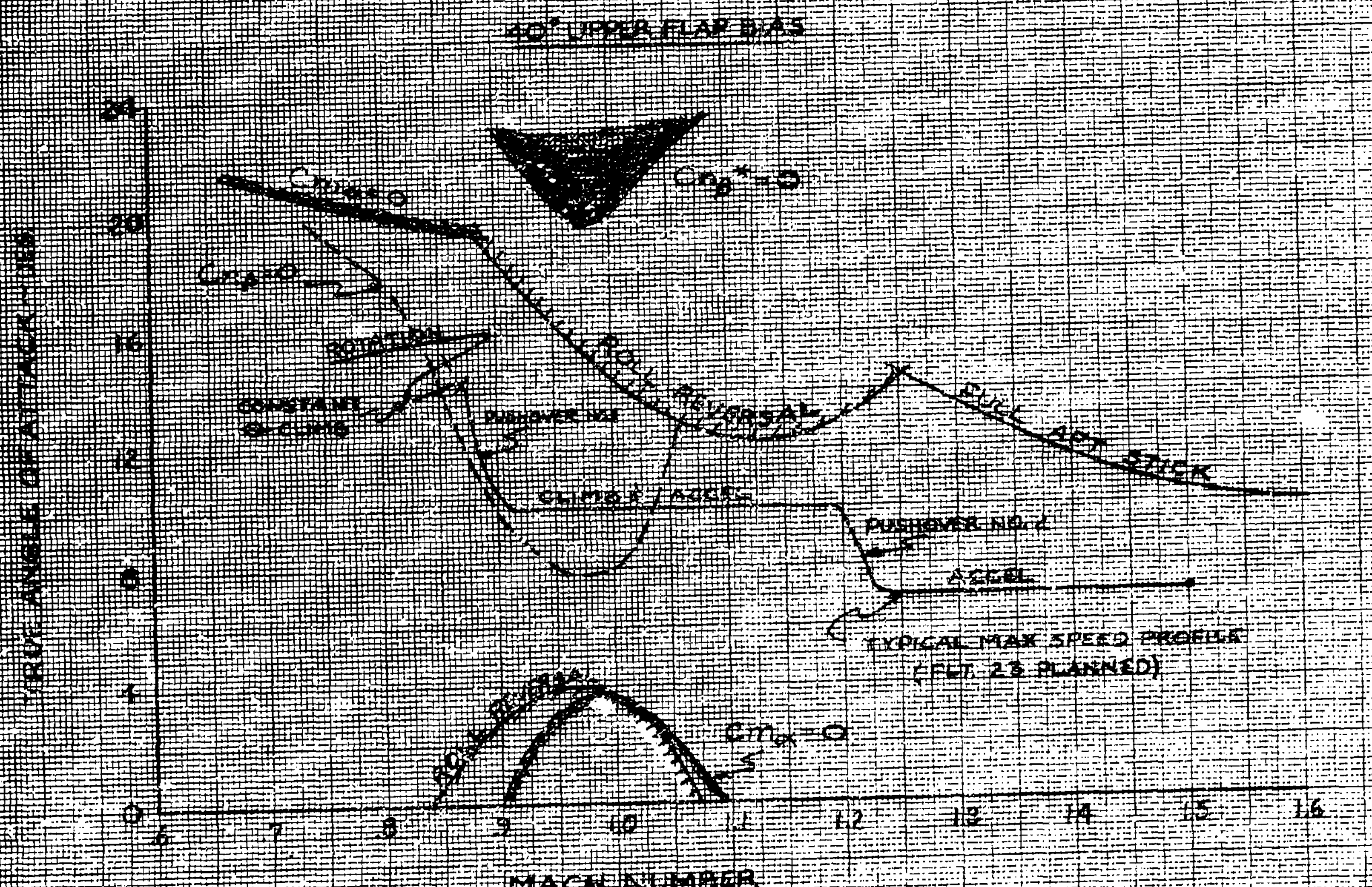


FIGURE 30. FLIGHT PLANNING BOUNDARIES

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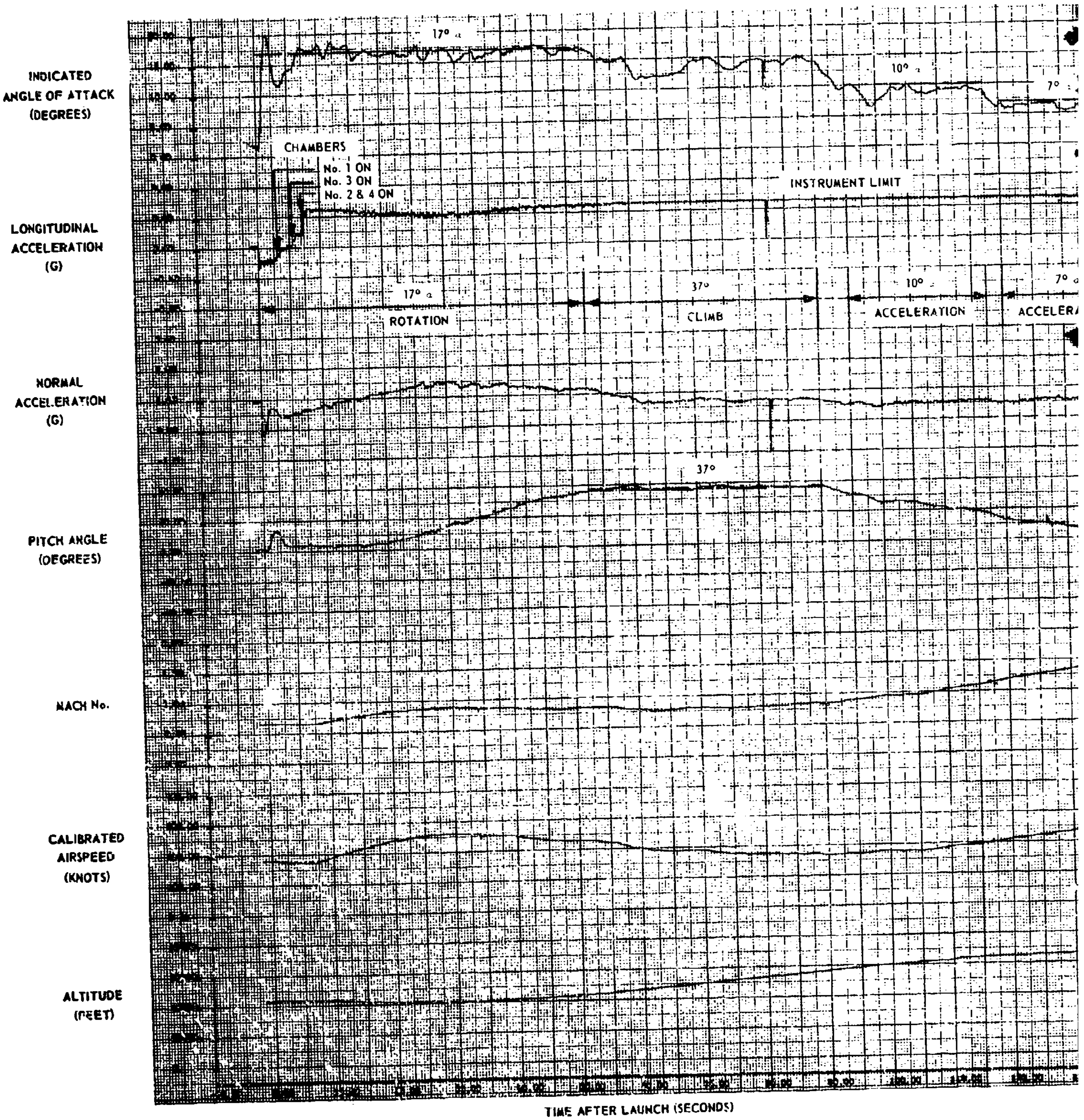
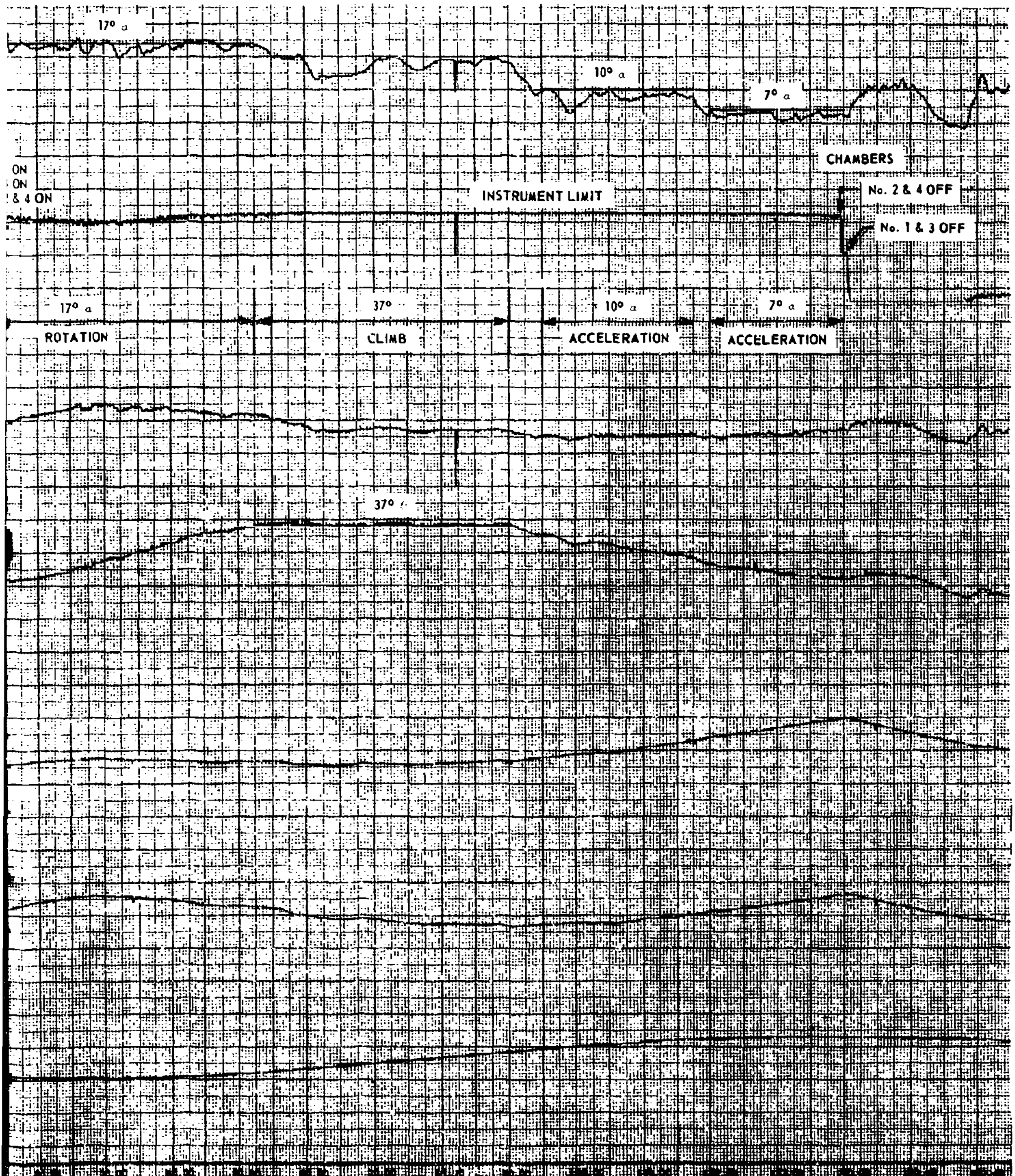


Figure 21 Time History of Performance Parameters - Flight 23



TIME AFTER LAUNCH (SECONDS)

Figure 31 Time History of Performance Parameters - Flight 23

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Thrust Effects

The exhaust plume of the XLR-11 rocket engine at the aft end of the lifting body, in between primary control surfaces, was believed to have had significant effects on the air flow characteristics over the vehicle. Evidence of aerodynamic effects due to thrust were apparent in the lateral-directional as well as longitudinal axes.

Flight determined values of C_{n_β} with power on and off at 0.80 to 0.85 Mach number indicated a decrease in directional stability with thrust on (reference 6). This trend in the 0.90 to 0.95 Mach number region was not definable. However, a large reduction in C_{n_β} with power on was confirmed at Mach numbers greater than 1.1 at α's above 10 degrees.

Effect of thrust on the longitudinal axis was significant and readily observable as pitch trim changes with selection of thrust chambers. After launch the pitching moment from thrust of all four chambers produced a noseup trim change of approximately 7 degrees α_i. Only a small portion of this trim change could be accounted for geometrically by the thrust vector acting below the vertical cg. This difference resulted in a considerable discrepancy between the simulator and aircraft in the lower flap required to maintain the 17 degrees α_i during the rotation and had to be considered in planning flights to prevent undesirable α overshoots. This was allowed for by launching the vehicle with the control surfaces set to cause the vehicle to trim at 10 degrees α_i before engine light. To compensate for the noseup trim change at low α the pilot required additional forward stick to the point of excessive arm extension. Prior to flight 15 a control system adjustment was made to improve the nosedown trim capability. In addition, a mounting bolt change was engineered to change the thrust line and to reduce the magnitude of the trim change prior to flight 21. This modification reduced the α trim change by 2 to 3 degrees. The source of the unexplained moment was assumed to be an aerodynamic effect produced by the engine exhaust plume. More detailed documentation of this subject may be found in reference 5.

During the first few powered flights, the vehicle's performance was better than predicted by the simulator. That is, the vehicle reached the planned Mach number in a shorter time than planned. Power-off drag data obtained up to that point had not defined any significant differences from wind tunnel values. Absence of accurate thrust values for the engine precluded determination of lift and drag with power on and also added an unknown to flight planning. In an effort to update the simulator based on flight data, a match of the actual flight profile and Mach number from flight 15 was accomplished on the simulator. This was done by duplicating the actual piloting techniques (α control, engine operation, etc.) as closely as possible. Systematic changes to the simulator were then tried to attempt to improve the match between the flight and simulator results. A thrust level change did not produce a good simulator match. A decrease in chord force coefficient by 0.02 was found to result in the best match. This effect accounts for the decrease in base drag with thrust on; an effect not established by wind tunnel tests. This same parameter has been included in simulations of other rocket powered aircraft (X-15 and HL-10). Although it can be considered somewhat empirical in nature, it was required to provide better simulation for flight planning. This correction of 0.02 to chord force due to de-

creased base drag was used in the simulation only when one or more chambers were operating. This remained a part of the simulation for the remainder of the program.

It should be noted that the engine in the X-24A configuration was strictly a means of achieving the required supersonic Mach number to perform glide tests. The ability of the X-24A configuration to perform a re-entry maneuver would not have been compromised by the effects of thrust discussed here. However, the impact of this effect on other vehicle configurations/missions should be considered during future design efforts.

Automatic Scheduling of the Control Surfaces

The control system design of the X-24A included a capability to automatically position the upper flap bias and rudder bias as a function of Mach number. The original design schedule of the upper flap bias and rudder bias versus Mach number is shown in figure 32.

Because of a lack of redundancy in the automatic system and in order to facilitate obtaining consistent and meaningful test data, the upper flap bias position was set by the pilot using the manual mode of operation during most of the test program.

The automatic upper flap bias versus Mach number schedule was modified late in the test program based on flight test knowledge of stability boundaries, approach and landing techniques, and the required speed brake capability in the landing pattern. As previously discussed the rudder bias schedule was changed from a function of Mach number to a function of upper flap bias position. These revised schedules are shown in figure 32. Although this automatic schedule was not demonstrated on an entire flight, the system was engaged for 53 seconds on flight 26 and operated satisfactorily over the range shown in figure 32. Additional discussion of this control system feature can be found in reference 8.

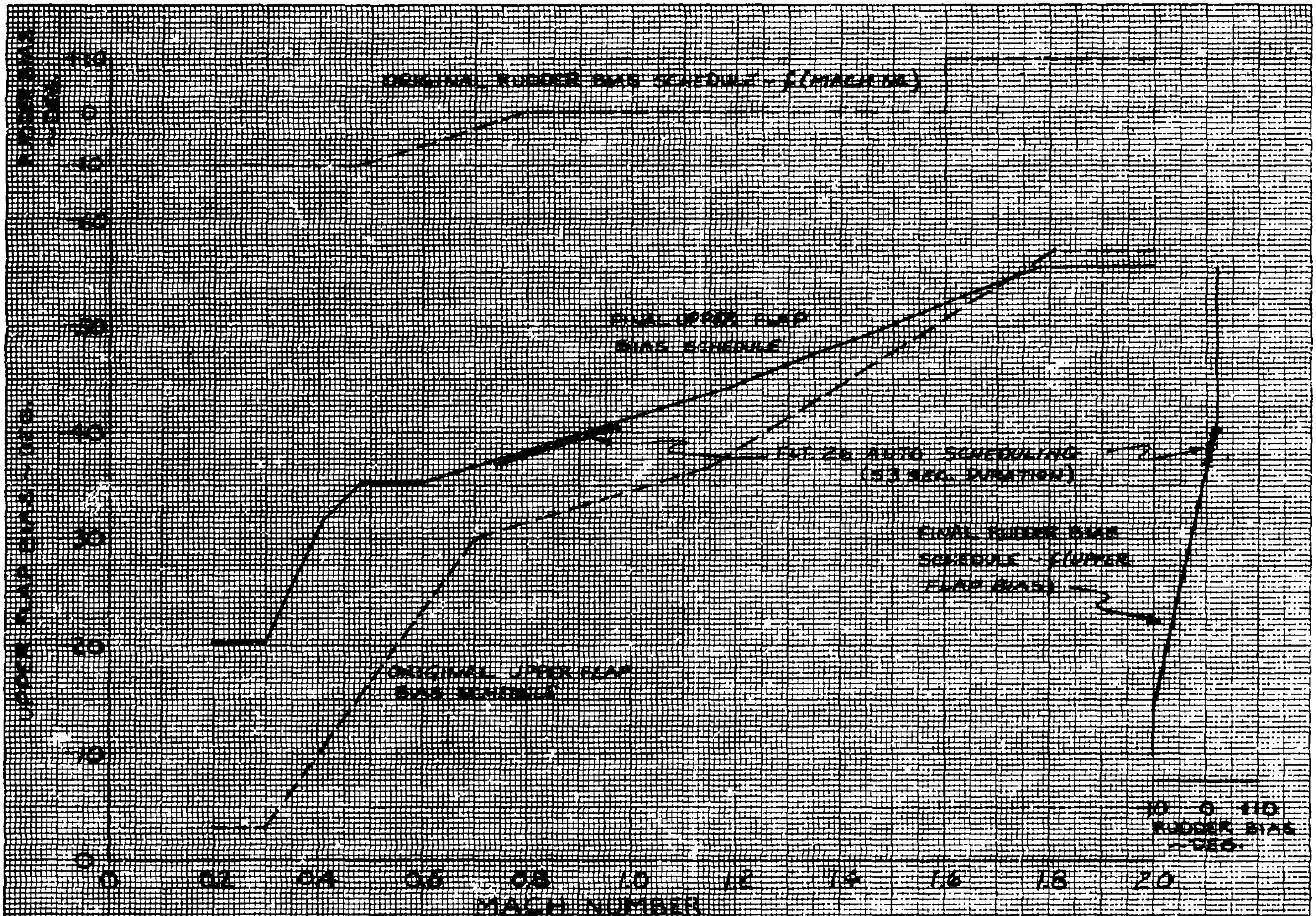


FIGURE 32 AUTOMATIC SCHEDULES OF THE CONTROL SURFACES

Energy Management

Energy management of the X-24A powered flights was achieved through detailed flight planning and close pilot adherence to the planned profile. Figure 33 depicts the accuracy which the planned maximum Mach number and altitude were achieved for each flight. The pilot performed the engine shutdown on normal profiles using indicated Mach number. With the exception of the alternate profiles (shaded symbols) which will be discussed later, the maximum Mach number was within a tenth of the planned value. An overshoot in Mach number of one tenth was not considered unreasonable in light of the overriding requirement to accomplish the test maneuvers. The maximum altitude consistently came out lower than planned; a 2,000-foot undershoot was common. Although not critical from an energy management standpoint, it was an annoying perturbation. Detailed post-program analysis did determine that values of lift coefficient (C_L) above 6 degrees α were lower than wind tunnel predictions (reference 4).

It was established during flight planning, that if the engine shutdown conditions were within reasonable tolerance bands, the pilot could complete the planned test maneuvers without concern about energy management. Then after the key data maneuvers were completed, energy management corrections could be made as required. The outer limit of the allowable shutdown deviation along the downrange track was normally ± 2 NM. Actual deviations from planned shutdown conditions are shown in figure 34. Note that the shutdown points for all normal profiles (open symbols) were within 1.5 NM. This degree of accomplishment greatly simplified the energy management task during the X-24A program and was primarily responsible for the large volume of excellent test data which was obtained during the very brief flying time of the program. The cross track deviation could easily be corrected by the pilot when time permitted and was not a significant factor in energy management. As already indicated and as shown in figure 34 as Δ altitude, the ability to be within 2,000 feet of the planned shutdown altitude was important to energy control. The deviations for the alternate profiles shown (solid symbols) are based on the difference between the actual and planned <u>alternate</u> profile shutdown conditions.

Examples of the tracks and profiles used during the powered flights are shown in figures 35 and 36. The first 11 powered flights were launched from the Palmdale launch area (figure 35) using Rosamond Dry Lake as launch lake. As higher energy flights were planned additional distance was required, therefore, the last seven flights were flown from the Cuddeback launch area (figure 36) using Cuddeback Lake as a launch lake. The actual launch points were displaced along the track shown, depending on the range required to accomplish the flight objectives. The ground track distance flown from between launch and the low key points from the actual Palmdale and Cuddeback launch points were 32 to 38 NM and 36 to 44 NM, respectively.

The maps shown in figures 35 and 36 are reduced copies of actual radar maps prepared for use in controlling the flights. The planned altitude profile and ground track were traced on the map by the simulator X-Y plotter while the planned flight was being simulated. The three lines shown crossing the altitude plot near maximum altitude are the early, normal and late shutdown guidelines. These lines represent the allowable downrange shutdown deviations. The slope of these lines was an attempt to provide a guide for off-nominal altitude compensation

(i.e., if lower than normal delay shutdown). During the flight, the pilot was advised of his position relative to the shutdown lines. The time between the early and late shutdown lines was approximately 20 seconds.

The effect of upper altitude winds on the planned profile was determined from the simulation between the launch point and the planned shutdown point. It was unrealistic to correct the glide portion of the profile for winds because of the significant effect piloting technique had on the energy management to achieve the desired low key. The launch points for 11 of the 18 powered flights were shifted along the track between 0.5 to 2.7 NM. The wind effect on the remaining seven flights was small enough to ignore. The predominate wind direction for the flight test area was from the west, therefore, the Palmdale track normally required an aft shift to compensate for winds. However, it was found that the amount of aft displacement was limited by the effect on the glide to Rosamond Dry Lake in event of an engine malfunction at launch. Wind correction limitations were not a problem at the Cuddeback launch point because the required shifts were closer to the launch lake. Energy management from shutdown to low key was based on profile and track advisory from the ground controller (amount above or below planned and distance right or left of track). The pilot responded to calls about the profile energy as described in the glide flight discussion with α and upper flap bias changes. In addition, the planned turn to downwind shown on the map was altered as dictated by the energy level approaching that point, i.e., early turn (cut the corner) for low energy and a late turn (swing wide) for high energy.

The requirement (based on stability margins) to be at or below 0.5 Mach number to perform the one step configuration change from -40 to -13 degrees upper flap bias somewhat restricted energy management. For a normal downwind airspeed of 200 knots, 0.5 Mach number occurred at 27,000 feet. This in turn dictated that the configuration change be approximately 3 to 4 NM from low key and did not leave very much altitude for energy adjustments. To illustrate the effect, a configuration change Mach number of 0.6 would have increased the altitude to 35,000 feet (for 200 KCAS) and separated the configuration-change point and low key by approximately 7 to 8 NM. Where range stretching dictated an early configuration change, the configuration was changed in steps as a function of Mach number to maintain sufficient upper flap bias for adequate stability as the Mach number decreased. The rule of thumb established was the Mach number/upper flap bias schedule shown below:

Mach No.	Upper Flap Bias (deg)
0.8	-35
0.7	-30
0.6	-20
0.5	-13

This application of altering the configuration (wedge angle) for energy management provided an effective speed brake below 0.6 Mach number for the X-24A. Considerable use of the speed brake feature was made below 15,000 feet while accomplishing the landing pattern to achieve the touchdown accuracy of $\pm 2,000$ feet presented in reference 1.

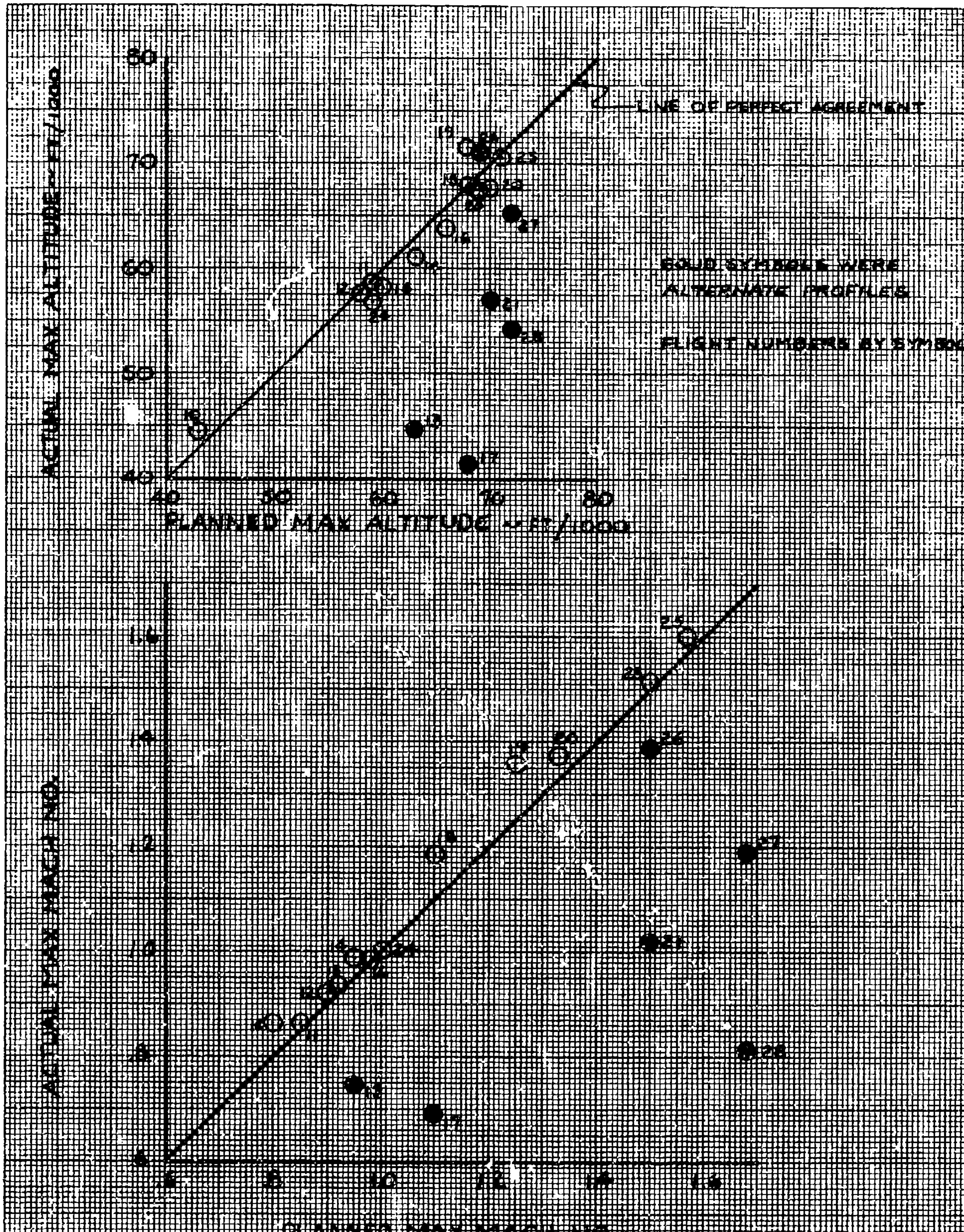


FIGURE 33. COMPARISON OF PLANNED & ACTUAL MAX MACH & ALTITUDE

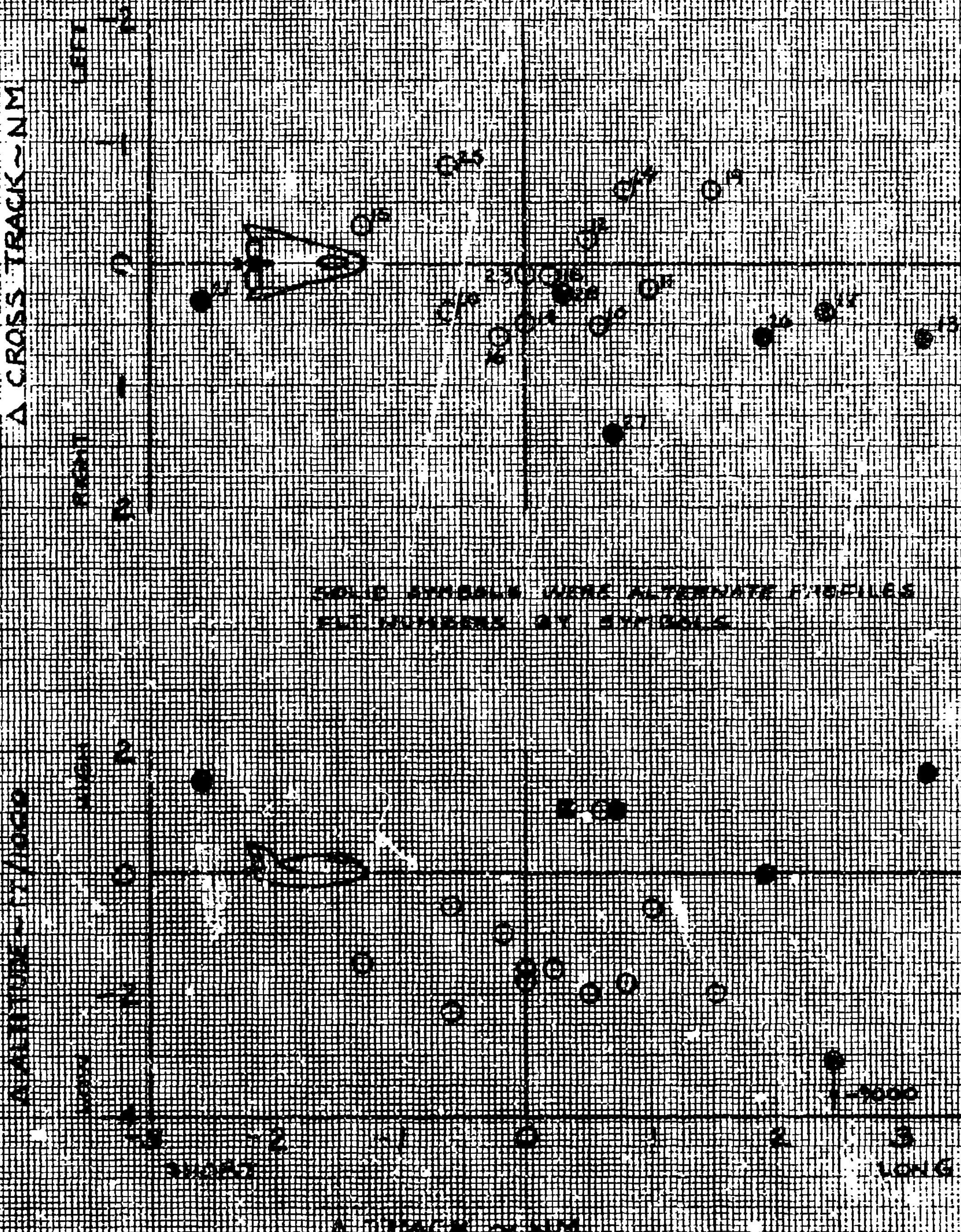


FIGURE 5A. ENGINE SHUTDOWN DISPERSION

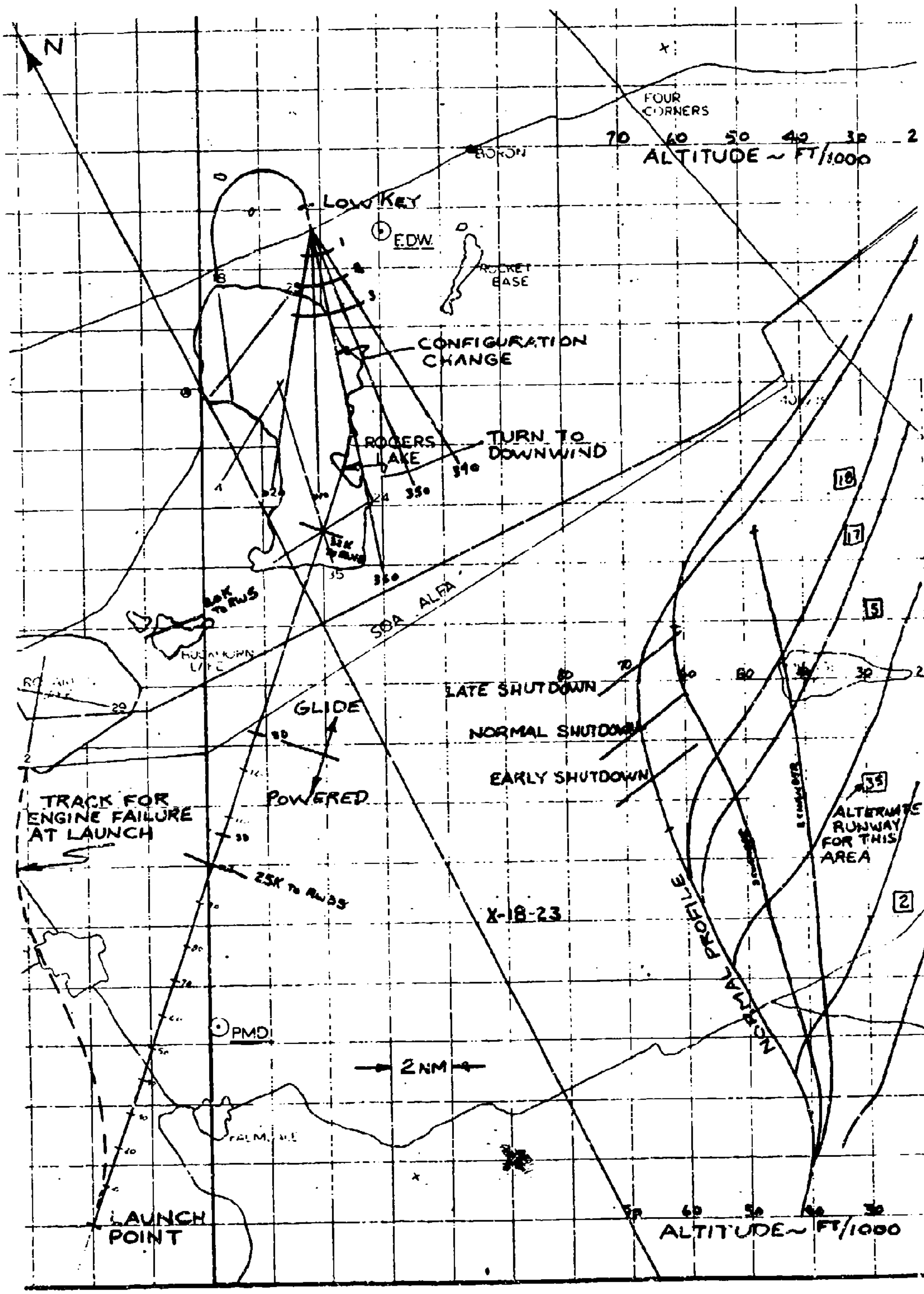


Figure 35 Ground Control Map of Palmdale Launch

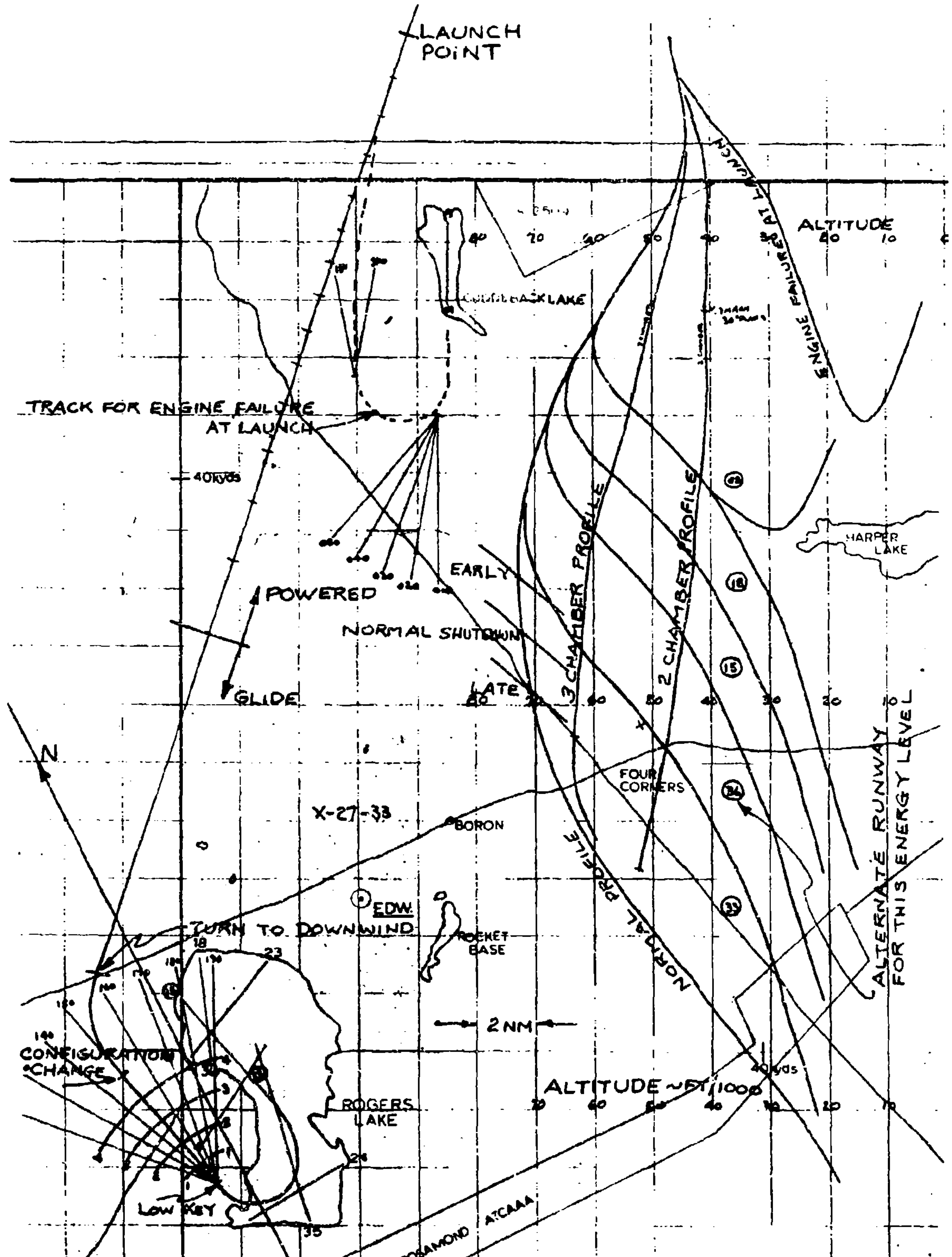


Figure 36 Ground Control Map of Cuddeback Launch

Alternate Profiles

The maps on figures 35 and 36 show alternate preplanned two- and three-chamber profiles. These were used as guides when alternate profiles were flown because of failure of individual rocket chambers to light. In addition, the two-chamber profile was to be flown in instances in which system failures after launch dictated a less demanding profile than the planned mission (for example, angle of attack or SAS malfunction). A one-chamber profile is not shown because insufficient thrust existed to maintain level flight. The plan, in this case, was to shutdown the single chamber, jettison propellants, and land at the launch lake.

Also presented on the radar map are lines of altitude versus range for glides to alternate runways after premature engine shutdown. The lines shown are for "break points" where energy would be adequate to accomplish a glide to either alternate runway identified on either side of a line: i.e., runway 35 or 5 (figure 35). This was considered the primary real time energy management aid to be used to recommend the best runway to the pilot for this type of alternate situation. In addition, the pilot knew the engine burntime that corresponded to the break points between alternate runways that could have been used as a guide in the event a radio and/or radar failure precluded ground control advice. The pilots also felt that they possessed a reasonable degree of visual energy management capability because of the experience obtained during F-104 simulations along the planned alternate profiles.

Alternate profiles, or significant variations from planned profiles occurred on 6 powered flights (13, 17, 21, 26, 27, and 28). Flights 13, 17, and 28 were two-chamber alternate profiles due to engine malfunctions. The -40 degrees upper flap bias configuration resulted in insufficient excess thrust to allow the vehicle to climb on two chambers at heavyweight conditions immediately after launch. The procedure was established to decrease the upper flap bias in steps as previously discussed although only a moderate climb was possible. On flight 13, the burntime available on two chambers was underestimated and the engine operated longer than expected. This was fortunate because the energy was thought to be somewhat marginal. The planning discrepancy explained the difference between planned and actual Δ track shown in figure 34. The two-chamber profile on flight 17 was also a delayed light situation. The two chambers were not obtained until 30 seconds after launch. This long delay was considered excessive and resulted in a profile 8,000 to 10,000 feet lower than planned. To compensate for the low altitude, the shutdown was intentially delayed to allow the vehicle to travel further down track to reach the normal energy condition. Flight 28 was another two-chamber alternate flight due to engine malfunctions and a disappointing last flight of the program.

Failure to obtain thrust from one chamber on flight 27 resulted in a successful three-chamber profile with alternate objectives being achieved.

After launch on flight 26 initial attempts to start the engine were unsuccessful. A successful start of all 4 chambers was finally accomplished about 30 seconds after launch with a resulting 9,000-foot altitude loss during the rotation. The planned objectives were met by flying

to propellant burnout, but at a slightly lower Mach number due to the excessive loss of altitude after launch. As shown in figure 34, the delayed engine light shifted the shutdown point (flight 26) downrange from the planned location.

Although initial igniter malfunctions of one chamber on flight 16 were experienced, a successful light was obtained on the third try. This 17-second delay did not have a significant effect on the planned conditions of the particular flight and was not considered an alternate profile. The cause of the engine difficulties experienced during the X-24A program are discussed in reference 2.

The alternate profile flown on flight 21 was a result of a failure of the pilot's angle of attack indicator. Operation of this gauge after launch on this flight was too erratic to be relied upon for the planned flight. Because of the proximity to α limits during a high speed flight, it was deemed unwise to fly the planned flight without adequate α information. The preplanned procedure was to shutdown two chambers and fly an alternate two-chamber profile. After initial attempts to use the erratic gauge the pilot finally concluded it was unusable and shut down two chambers. However, the engine had burned for over 74 seconds on 4 chambers so the resulting profile fell between the 2- and 3-chamber profiles. During this flight ground control provided numerous advisories on angle of attack based on telemetry data.

Jettison Fire

Inspection of the vehicle immediately after landing on flight 17 revealed fire damage in the engine area. Many aluminum lines on the engine had burned or melted, all four flaps showed some degree of damage, the engine mount was distorted and electrical wiring burned.

Detailed data analysis led to the conclusions that the fire had occurred 10 seconds after engine shutdown during jettison of the remaining propellants. Photographs from chase aircraft showed extensive recirculation of the jettisoned propellants in the base area (figure 37 is a photograph of LOX jettison). One theory was that the hot engine nozzle provide the ignition source. In an attempt to prevent this from happening again, the jettison tubes were modified to provide further separation between the two propellants (figure 38); procedures were changed so that the pilot would wait at least 20 seconds after engine shutdown prior to jettisoning propellants, and LOX and fuel would be jettisoned separately.

During the time required to repair the damage, a thermocouple was added to the No. 1 chamber nozzle extension. The resulting data obtained on the next flight is shown in figure 39. The temperature stabilized at a value of 1,750 degrees F during engine operation. As can be seen by the cooling cycle after shutdown; at 20 seconds the temperature was still excessive at 1,400 degrees F. It was hoped to delay jettison until the nozzles were sufficiently cool to preclude ignition. For future flights the ground rule was to delay jettison 100 seconds after shutdown then jettison each propellant separately. No further jettison fires were encountered during the X-24A program.

Experience since that time with the M2-F3 vehicle provided additional information to this problem. The M2-F3 experienced two jettison

fires with similar damage to aft located control surfaces. The last fire occurred after a brief engine run (7 seconds) and after 117 seconds delay between shutdown and jettison. The similar factors of all three flights were that none went above 45,000 feet and the helium bleed flow to the chambers was shut off shortly after shutdown. Ground test showed that the residual fuel in the chambers after a normal shutdown can burn for extremely long durations (in excess of 230 seconds without helium bleed). The afterfire in the chambers was the most probable source of ignition of the jettison fires. Lack of sufficient oxygen in the atmosphere at high altitudes on other X-24A flights prior to flight 17 may have been inadequate to support an afterfire and no jettison fire occurred.

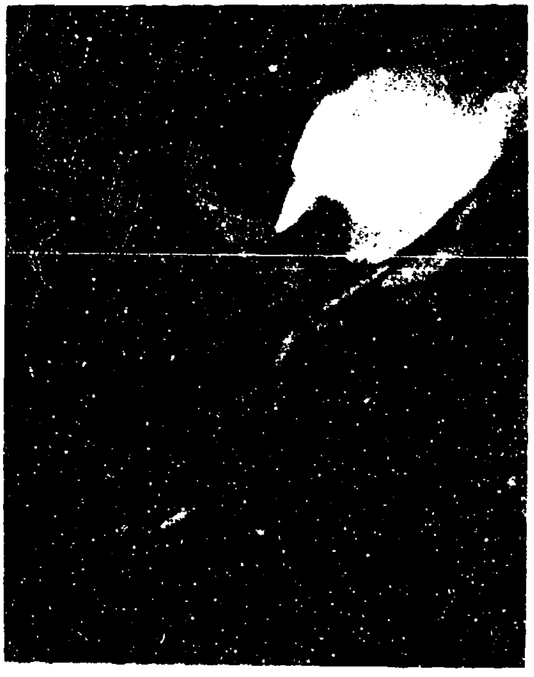


Figure 37 Inflight Photo of LOX Jettison

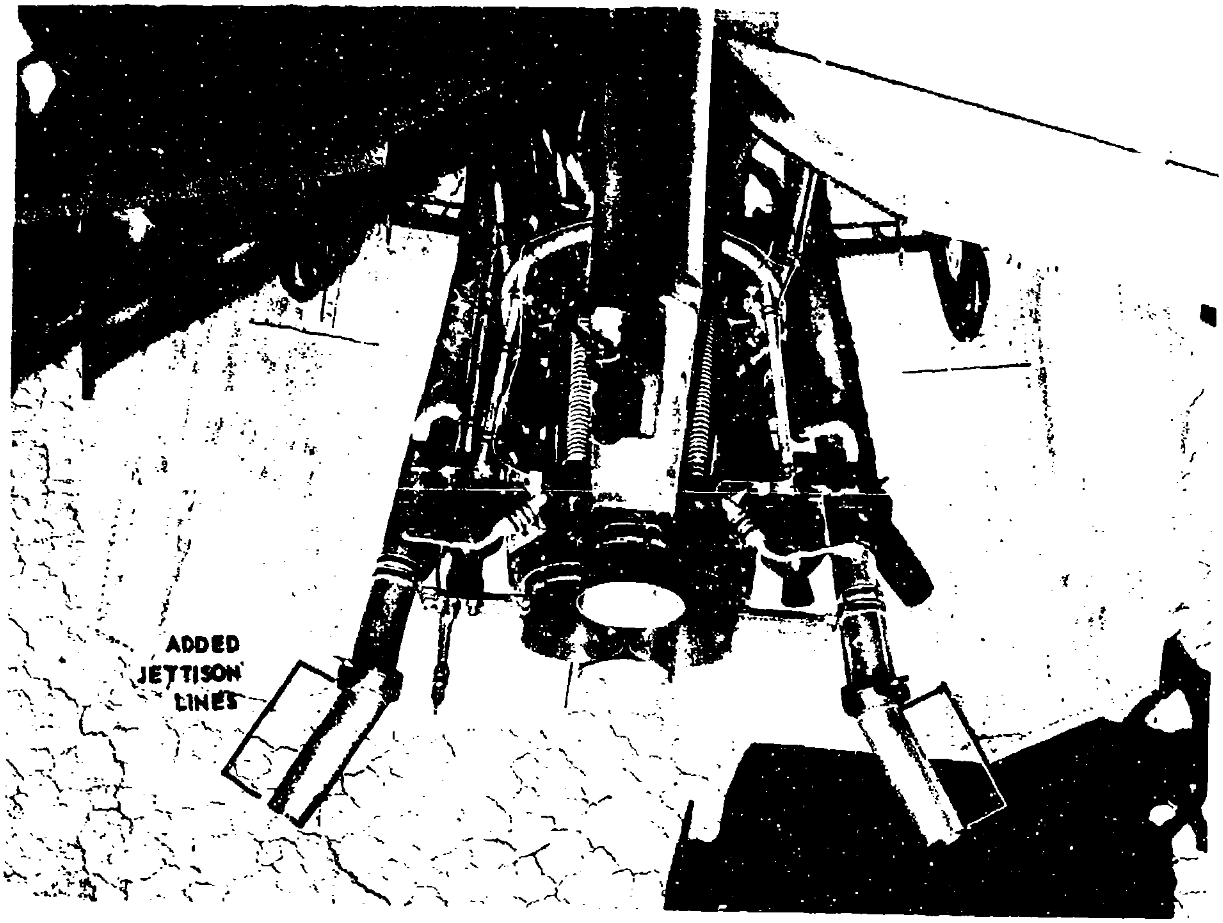


Figure 38 Photo of Modified Jettison Lines

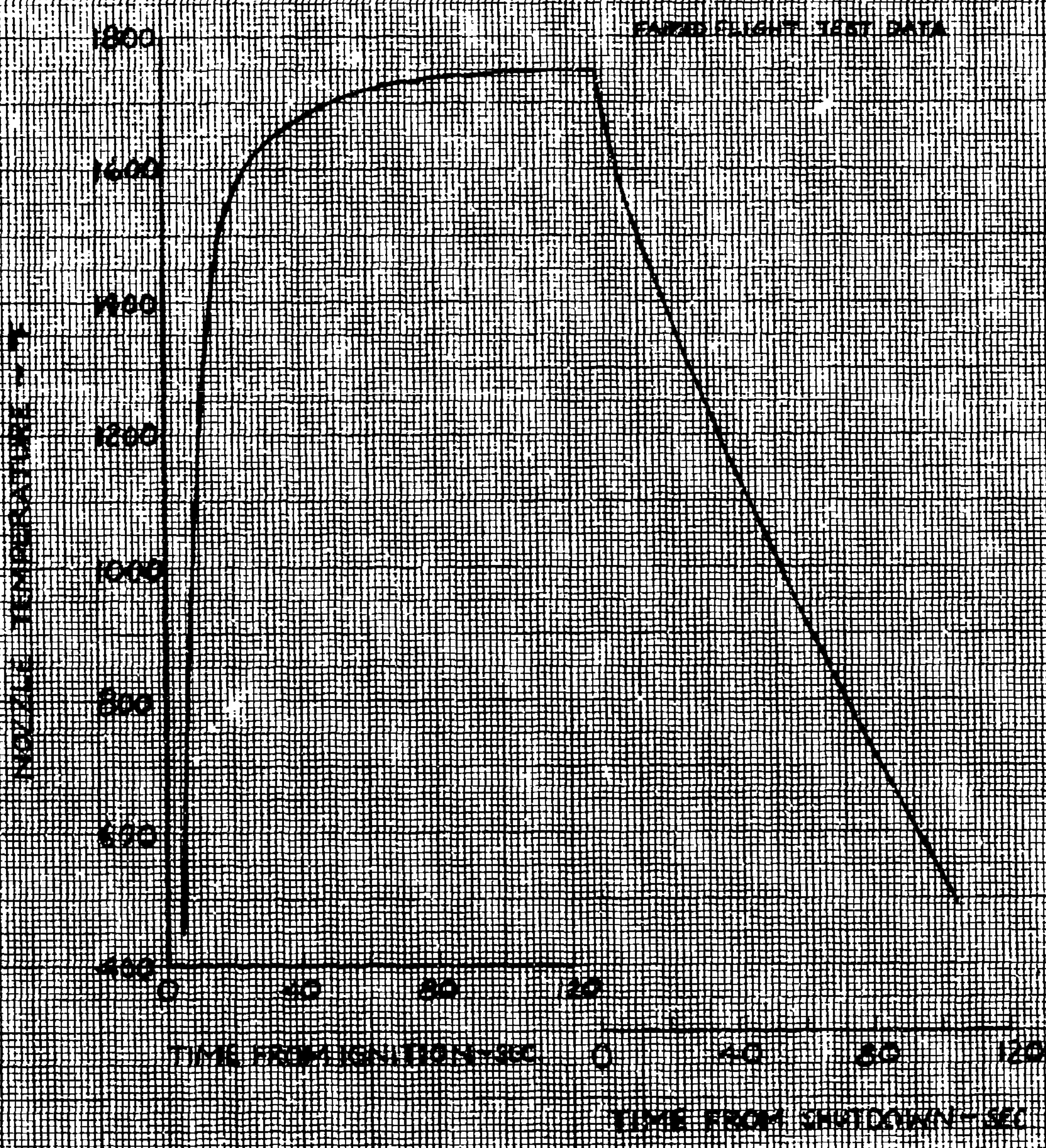
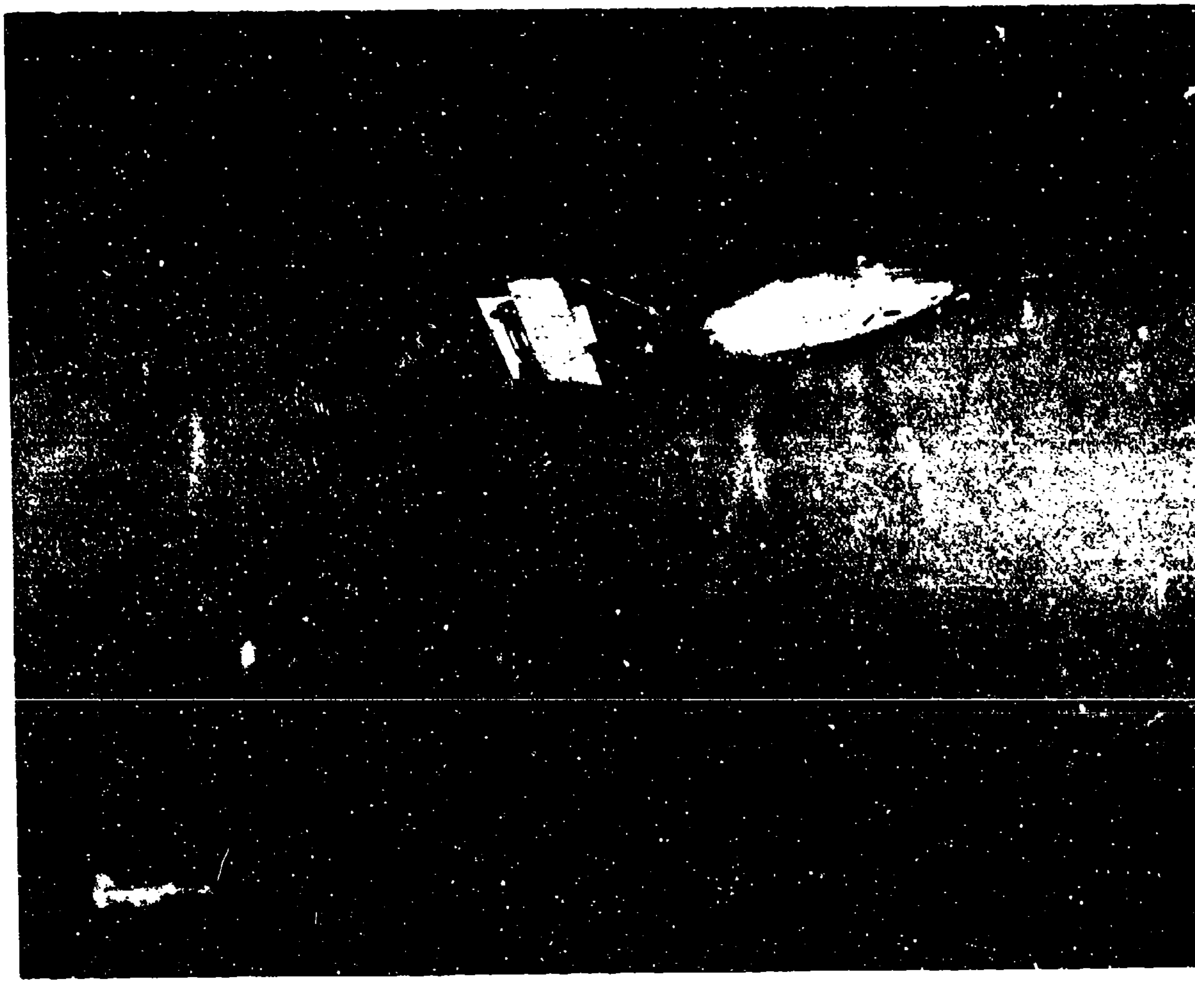


FIGURE 39. XLR-11 NOZZLE TEMPERATURE DURING FLIGHT



Envelope Explored

The envelope of Mach number versus angle of attack explored during the flight test program is presented in figure 40. The relationship of flight experience to the flight planning limits for the -40 degrees upper flap bias configuration can readily be seen.

The plot of Mach number versus altitude of all X-24A powered flights is documented in figure 41. A flight log of each individual flight is included in appendix V. A maximum performance flight to engine burnout was not performed during the X-24A program. The maximum Mach number of 1.6 occurred on a flight (25) planned for engine burnout at 1.57 Mach number. When engine burnout did not occur as planned, the pilot shut down the engine at 1.6 Mach number as prebriefed. Engine problems on the last two X-24A flights (27, 28) precluded attempts to obtain maximum Mach number.

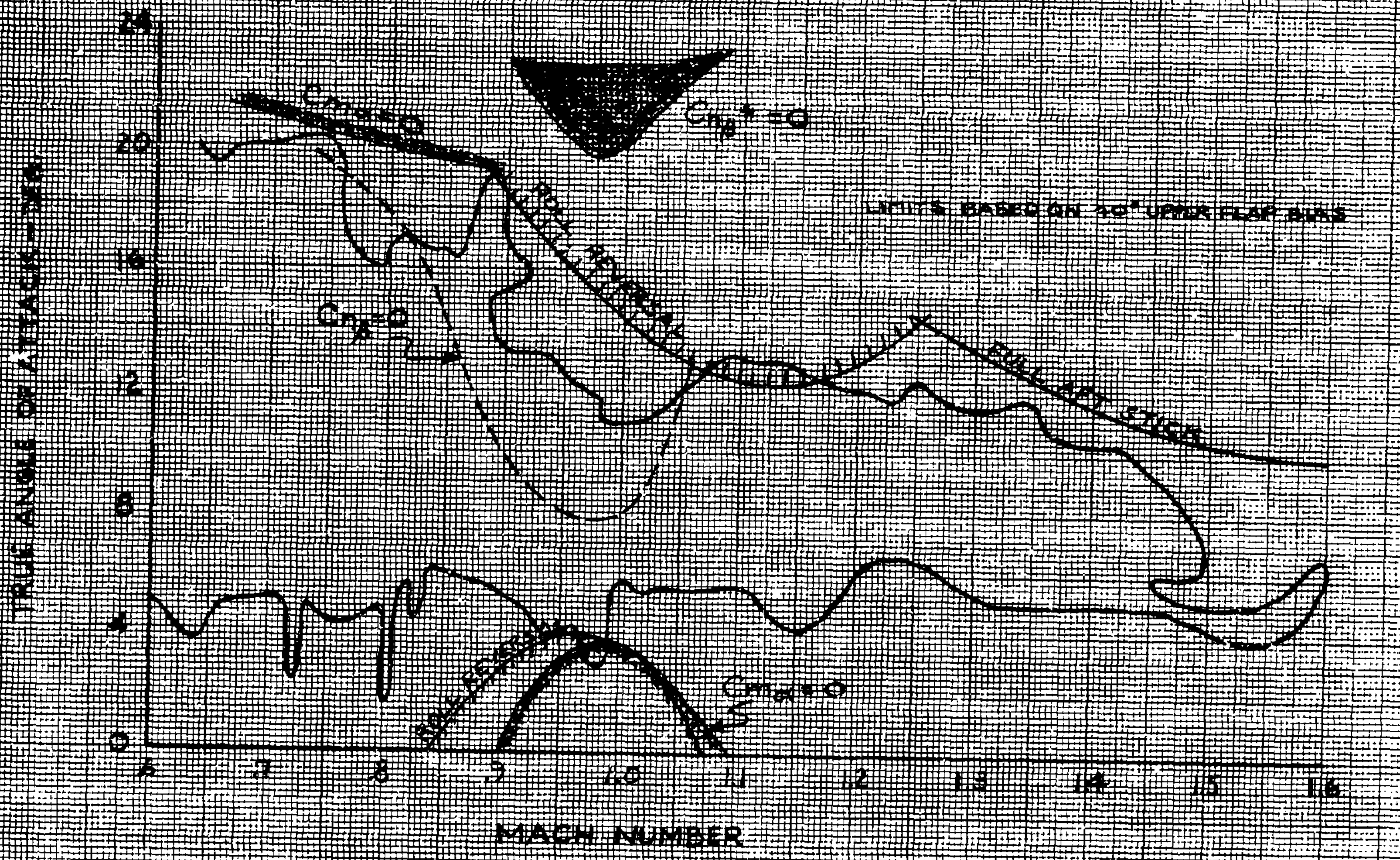


FIGURE 40. MACH/α FLIGHT ENVELOPE

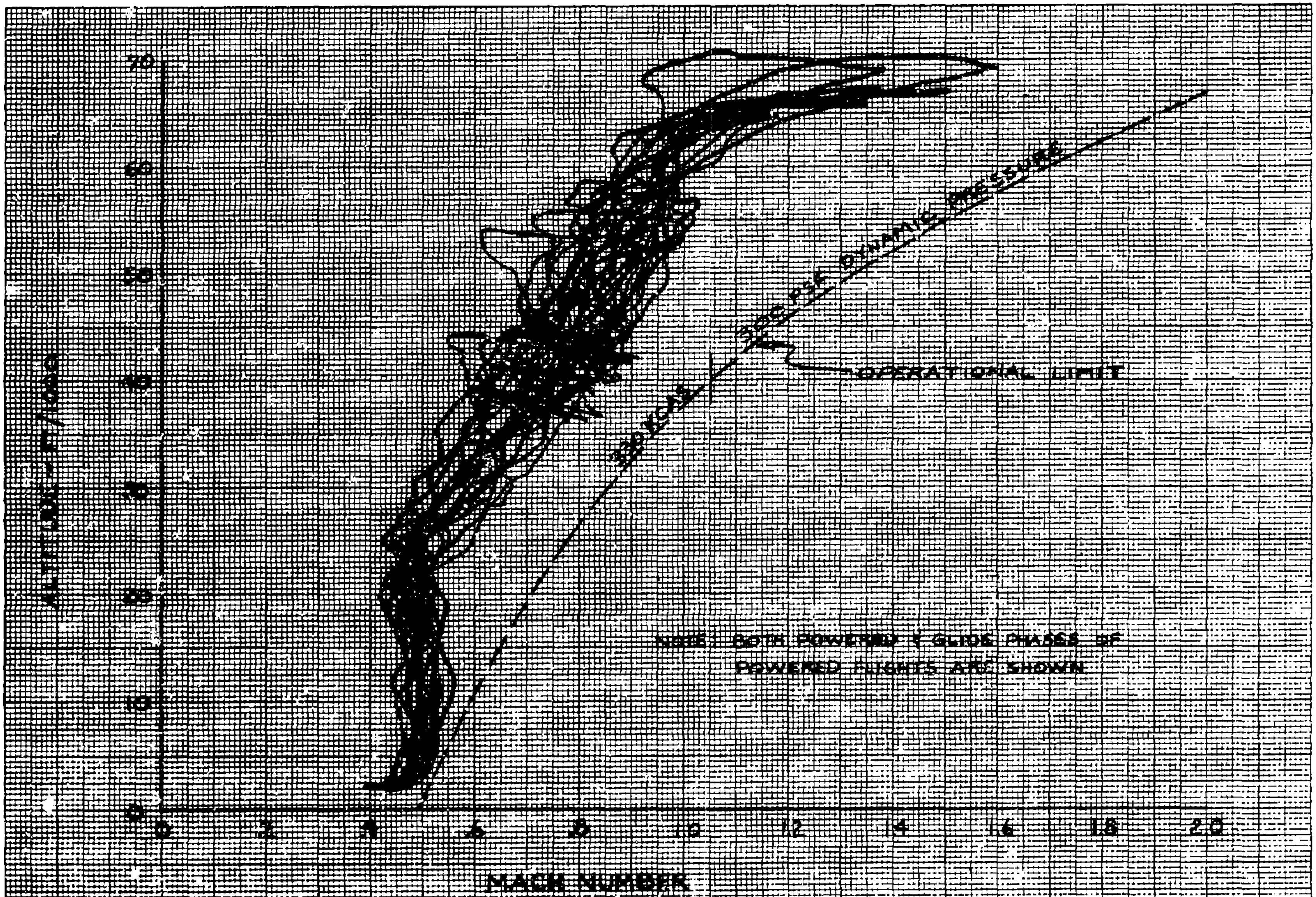
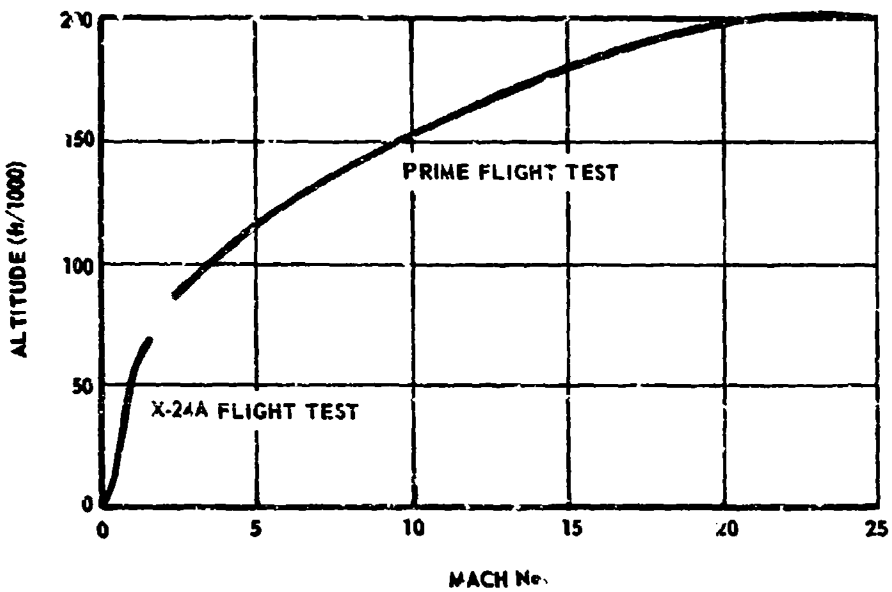


FIGURE 41. POWERED FLIGHT ENVELOPE

CONCLUSIONS

The X-24A flight test program successfully demonstrated the ability of the SV-5 lifting body configuration to be piloted from 1.6 Mach number to a horizontal landing. These results along with the successful re-entry from orbital velocity of the same basic aerodynamic configuration during the PRIME program, completed flight test efforts of a program that began as a research effort to develop technology in lifting re-entry from earth orbit.



X-24A flight test program produced test results to allow de- porting over the following ranges of parameters and conditions:

ngs

Ma[illegible]m L/D	3.0 to 4.3
Approach L/D	1.8 to 3.4
Approach γ	-14.5 to 24.5
Approach KCAS	270 to 310
Approach KRA	15 to 50 pct and automatic $f(\alpha)$
Lower flap for pitch and roll control	
Upper flap for pitch and roll control	
Crosswind	up to 10 kt
Turbulence	light
SAS-off approach	

Stability and Handling Qualities	
α	2 to 19 deg
Mach number	0.5 to 1.6
Upper flap bias	-10 to -40 deg
Rudder bias	+2 to -10 deg
Thrust	on and off

Performance	
α	2 to 19 deg
Mach number	0.26 to 1.60
Upper flap bias	-8 to -40 deg
Rudder bias	+2 to -10 deg

The design of the X-24A control system with its variable control system features provided: (1) the opportunity to explore several aerodynamic variations of the basic configuration and (2) a means to easily make changes/adjustments to improve vehicle flight characteristics.

Significant differences between flight test and wind tunnel derivatives were determined. These differences usually resulted in degraded vehicle handling qualities that required control system changes.

The envelope expansion program was safely conducted on a vehicle with low levels and, at some flight conditions, negative values of C_{n_β} through the incremental approach provided by use of the six-degree of freedom simulator and between flight derivative determination.

Differences in the derivative C_{n_β} were determined between power-on and power-off at the same flight conditions. Unaccountable changes in longitudinal trim were experienced with power on. These differences were believed to have been the result of aerodynamic flow changes on the vehicle as a result of the rocket exhaust plume.

Some of the flight conditions (M, α, $\bar{q}$) experienced during powered flight to reach the required test conditions were near known boundaries and resulted in degraded flying characteristics. Flight at these conditions would not necessarily be required during a gliding re-entry. However, future powered vehicles with similar propulsion/aerodynamic configuration should consider these effects.

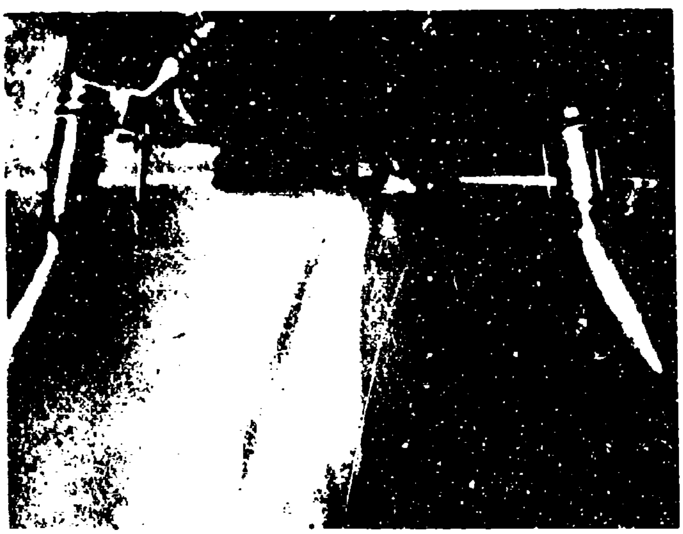
Use of the fixed base simulator to correct planned ground track and profile deviations due to known upper altitude winds was an important refinement to flight planning and conduct. Reduction of wind-caused deviations minimized profile corrections that would have detracted from planned data maneuvers.

APPENDIX I

X-24A INSTRUMENTATION

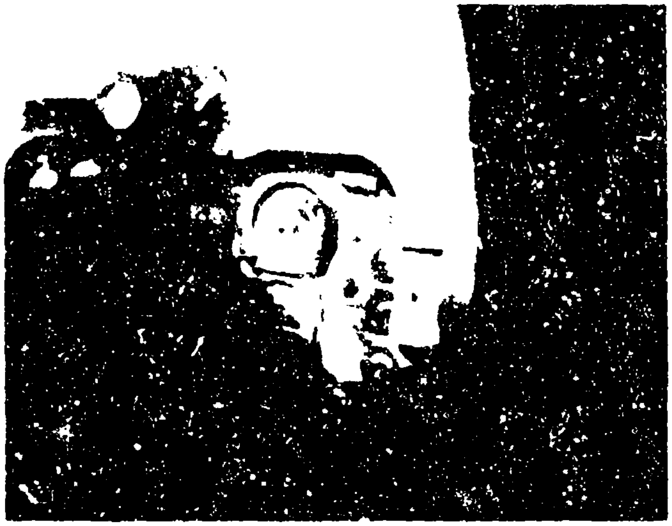
VIEW OF INSIDE R/H FIN FROM CENTER FIN CAMERA WITH 160 DEGREE FISHEYE LENS (FLIGHTS 5 THRU 8)

VIEW OF INSIDE R/H FIN FROM CENTER FIN CAMERA WITH 9MM LENS (FLIGHTS 12 THRU 25)

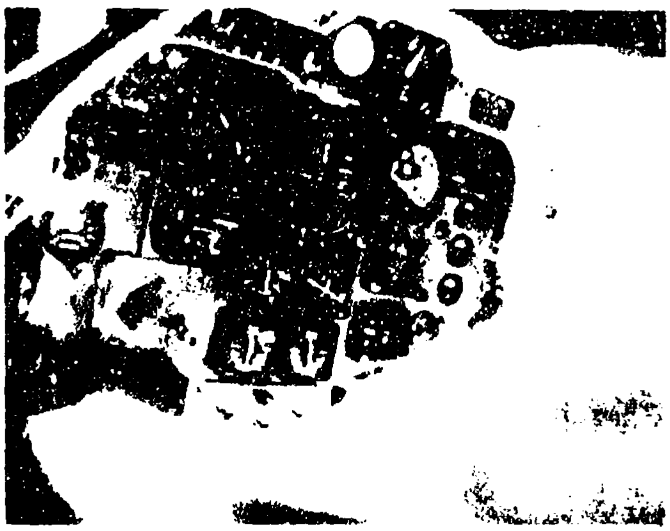


VIEW OF XLR-11 ENGINE NOZZLES FROM CENTER FIN CAMERA WITH 9MM LENS (FLIGHTS 26 THRU 28)

Figure 1 Field of View from Airborne Cameras



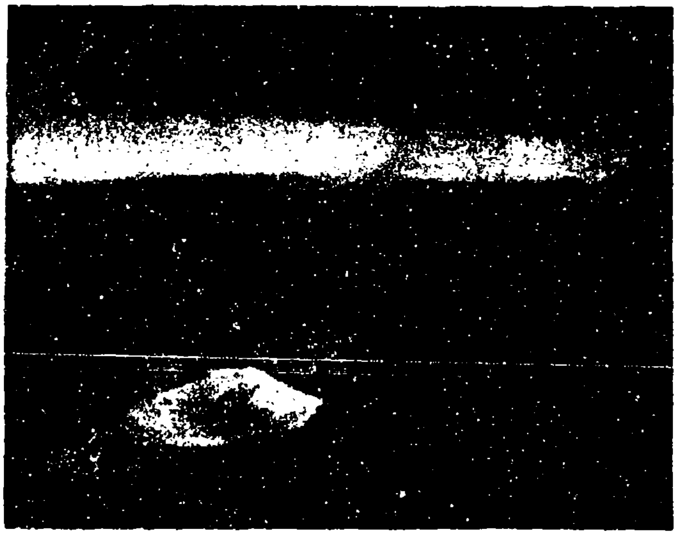
VIEW OF COCKPIT PANEL FROM CAMERA MOUNTED R/H CONSOLE (FLIGHTS 1 THRU 12)



VIEW OF COCKPIT PANEL FROM CAMERA MOUNTED ON L/H CONSOLE (FLIGHTS 13 THRU 28)

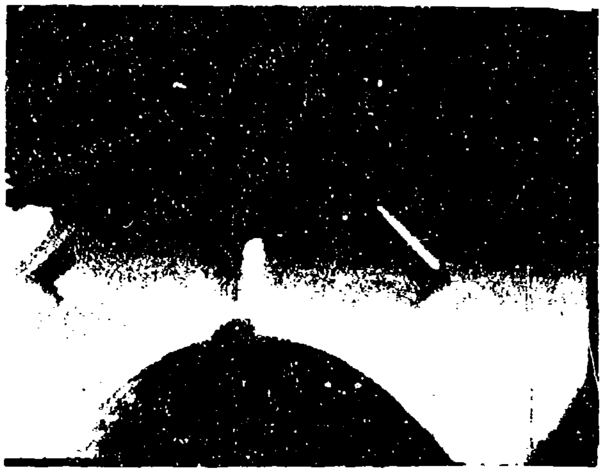
VIEW OF LOWER FLAPS AND GROUND FROM LOWER FUSELAGE CAMERA WITH 160 DEGREE FISHEYE LENS (FLIGHTS 3 THRU 8)

Figure 1 (Continued)



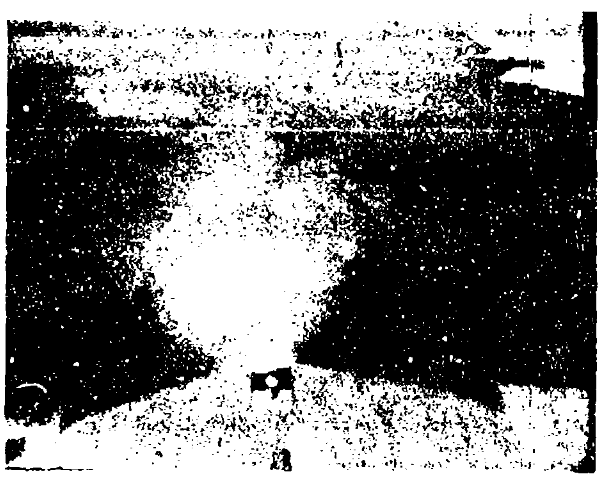
VIEW TOWARDS FLIGHT PATH FROM CAMERA MOUNTED
IN NOSE (FLIGHTS 23, 24, 25, AND 26)

Figure I (Continued)



VIEW OF LAUNCH SEPARATION FROM CAMERA MOUNTED AFT ON PYLON ADAPTER

VIEW OF PRELAUNCH AND LAUNCH EVENTS FROM CAMERA MOUNTED IN AFT OF THE NB-52



ALTERNATE VIEW OF LAUNCH SEPARATION FROM AFT PYLON CAMERA

VIEW OF LAUNCH SEPARATION FROM CAMERA MOUNTED FORWARD ON THE PYLON ADAPTER

Figure 2 (Concluded)

Table I

MAIN FRAME INSTRUMENTATION LINEUP

VEHICLE X-24A | FLT X-23-28 | SUBCOM S/N 511 | CT-77 S

CHAN No	PARAMETER Description	Range	TRANSDUCER S/N	Type	Range	Calib Date	Period	INST COMPT DISC	Type	Ch
1	SUB-COMM (CHAN 11, 31, 51, 71)									
2	HM-201 L/H UPPER RUDDER H/M	12K in-lb	NSN	C12-144		3/2/70	12 Mo	1	S/G	1A
3	HM-203 R/H UPPER RUDDER H/M	12K in-lb	NSN	C12-144		3/2/70	12 Mo	1	S/G	1B
4	HM-205-L/H LOWER RUDDER H/M	16K in-lb	NSN	C12-144		3/2/70	12 Mo	1	S/G	1C
5	SUB-COMM (CHAN 12, 32, 52, 72)									
6	HM-208-R/H LOWER RUDDER H/M	16K in-lb	NSN	C12-144		3/2/70	12 Mo	1	S/G	1D
7	HM-210-L/H LOWER FLAP H/M	30K in-lb	NSN			9/28/70	12 Mo	1	S/G	3A
8	HM-211-R/H LOWER FLAP H/M	30K in-lb	NSN			9/28/70	12 Mo	1	S/G	3B
9	SUB-COMM									
10	HM-214 L/H UPPER FLAP H/M	40K in-lb	NSN	C12-144		11/30/70	12 Mo	1	S/G	3C
11	HM-215 R/H UPPER FLAP H/M	40K in-lb	NSN	C12-144		11/30/70	12 Mo	1	S/G	3D
12	VT-101C L/H FIN FWD SHEAR (Amp)		NSN	ROSETTE		1-16-68	12 Mo	5	S/G	4A
13	SUB-COMM									
14	VT-101A L/H FIN FWD SHEAR		NSN	ROSETTE		1-16-68	12 Mo	5	S/G	4B
15	VT-106A L/H FIN AFT SHEAR (Amp)		NSN	ROSETTE		1-15-68	12 Mo	5	S/G	4C
16	VT-106C L/H FIN AFT SHEAR		NSN	ROSETTE		1-15-68	12 Mo	5	S/G	4D
17	SUB-COMM									
18	VT-108 L/H FIN FWD BENDING		NSN	C12-124		1-16-68	12 Mo	1	S/G	5A
19	VT-112 L/H FIN AFT BENDING		NSN	C12-124		1-16-68	12 Mo	1	S/G	5B
20	CVT-113A CENTER FIN FWD SHEAR		NSN	ROSETTE		1-15-68	12 Mo	5	S/G	5C
21	SUB-COMM									
22	CVT-117C CENTER FIN AFT SHEAR		NSN	ROSETTE		1-15-68	12 Mo	5	S/G	5D
23	CVT-119 CENTER FIN FWD BENDING		NSN	C12-124		1-16-68	12 Mo	1	S/G	8C
24	YAW VELOCITY	±20°/sec	L/4341	US TIME	±40°/sec	12-14-70	6 Mo	4	F/T	21C
25	SUB-COMM									
26	CVT-123 CENTER FIN AFT BENDING		NSN	C12-124		1-16-68	12 Mo	1	S/G	8D
27	RADAR ALTITUDE RATE	±300°/sec				7-23-70	6 Mo	1	F/T	6D
28	SAS CHANNEL B ROLL RATE	±22°/sec		SAS		4-7-70	6 Mo	4	F/T	29A
29	SUB-COMM									
30	SAS CHANNEL B YAW RATE	±22°/sec		SAS		4-7-70	6 Mo	4	F/T	29B
31	DIGITAL INPUT							5	—	—
32	DIGITAL INPUT							5	—	—
33	SUB-COMM									
34	L/H UPPER FLAP POSITION	4°-57°	175	5 ~~36~~ CPT		10-21-70	4 Mo	3	CPT	26A
35	DIGITAL INPUT							5	—	—
36	DIGITAL INPUT							5	—	—
37	SUB-COMM									
38	DIGITAL INPUT							5	—	—
39	DIGITAL INPUT							5	—	—
40	L/H UPPER RUDDER POS	±25°	131	5°CPT		12-18-70	4 Mo	3	CPT	25A

Table I

RUMENTATION LINEUP

DATE 18 FEB 71	Page 1 of 4

		CT-77 S/N	XMTR S/N	P/A S/N	INST ENGR W. CLIFTON

..d	[redacted]	INST COMPT DISC	SIGNAL CONDITIONING Type	Ch	Conn & Pins IN	OUT	Ra	Rd	Rcal	Sig Level	FILTER 3db Cutoff	db/Oct	Sample Rate	CT 77 Ch	Sub Com & Ch
[redacted]														1	
No		/	S/G	1A	2-K,f,c,P	1Y,b	0	∞	100K	Low	40 CPS	6	200	2	
No		/	S/G	1B	2-m,h,d,r	1e,j	0	∞	100K	Low	40	6	200	3	
No		/	S/G	1C	2-n,j,e,s	1n,s	6190	1600	100K	Low	40	6	200	4	
[redacted]														5	
No		/	S/G	1D	2-w,v,t,x	1-v,x	6190	1600	100K	Low	40	6	200	6	
No		/	S/G	3A	1-H,D,A,L	1-A,D	5000	4000	100K	Low	40	6	200	7	
No		/	S/G	3B	1-J,E,B,M	1-H,L	5000	4000	100K	Low	40	6	200	8	
[redacted]														9	
No		/	S/G	3C	1-K,F,C,N	1-PT	10K	5000	50K	Low	40	6	200	10	
No		/	S/G	3D	1-W,T,P,Z	1-WZ	10K	5000	50K	Low	40	6	200	11	
No		5	S/G	4A	2-K,F,C,N	1-m,r	0	∞	600K	Low	40	6	200	12	
[redacted]														13	
No		5	S/G	4B	2-W,T,P,Z	1-c,f	0	∞	100K	Low	40	6	200	14	
		5	S/G	4C	2-X,U,R,a	1-K,N	0	∞	300K	Low	40	6	200	15	
No		5	S/G	4D	2-Y,V,S,b	1-S,V	0	∞	100K	Low	40	6	200	16	
[redacted]														17	
No		/	S/G	5A	1-X,U,R,a	1-c,f	0	∞	100K	Low	40	6	200	18	
No		/	S/G	5B	1-Y,V,S,b	1-k,p	0	∞	100K	Low	40	6	200	19	
No		5	S/G	5C	1-k,f,c,p	1-t,w	0	∞	100K	Low	40	6	200	20	
[redacted]														21	
No		5	S/G	5D	1-m,h,d,r	1-B,E	0	∞	100K	Low	40	6	200	22	
No		/	S/G	8C	3-K,F,C,N	2-P,T	0	∞	100K	Low	40	6	200	23	
No		4	F/T	21C	10-n,e	5-n,s	30K	180	NONE	Low	40	6	200	24	
[redacted]														25	
No		/	S/G	8D	3-W,T,P,Z	2-W,Z	0	∞	100K	Low	40	6	200	26	
No		/	F/T	6D	4-w,t	2-v,x	100K	100	NONE	Low	40	6	200	27	
No		4	F/T	29A	12-K,N	6-m,t	100K	150	NONE	Low	40	6	200	28	
[redacted]														29	
No		4	F/T	29B	12-W,Z	6-C,F	100K	150	NONE	Low	40	6	200	30	
		5	—	—	—	—	—	—	—	HIGH	—	—	200	31	
		5	—	—	—	—	—	—	—	HIGH	—	—	200	32	
[redacted]														33	
No		3	CPT	26A	12-c,k,p	6Y,b	0	∞	1800/200	HIGH	40	6	200	34	
		5	—	—	—	—	—	—	—	HIGH	—	—	200	35	
		5	—	—	—	—	—	—	—	HIGH	—	—	200	36	
[redacted]														37	
		5	—	—	—	—	—	—	—	HIGH	—	—	200	38	
		5	—	—	—	—	—	—	—	HIGH	—	—	200	39	
No		3	CPT	25A	9-X,R,a	5-c,f	0	∞	1800/200	HIGH	40	6	200	40	

2

Table I (Concluded)

VEHICLE X-24A | FLT X-23-28 | SUBCOM S/N | CT-77 S/N

CHAN No	PARAMETER Description	Range	TRANSDUCER S/N	Type	Range	Calib Date	Period	INST COMPT DISC	Type	Ch
41	SUB-COMM									
42	R/H UPPER RUDDER POS	±25°	133	5" CPT		12-18-70	4 Mo	3	CPT	25C 9
43	L/H LOWER RUDDER POS	±10°	130	5" CPT		12-18-70	4 Mo	3	CPT	25B 9
44	R/H LOWER RUDDER POS	±10°	132	5" CPT		12-18-70	4 Mo	3	CPT	25D 9
45	SUB-COMM									
46	R/H UPPER FLAP POS	4°-57°	176	5¾" CPT		10-21-70	4 Mo	3	CPT	26C 12
47	ANGLE OF SIDESLIP	± 18°	NSN	Boom		12-18-70	4 Mo	4	F/T	23B 9
48	ANGLE OF ATTACK	-13°-+20	NSN	Boom		12-18-70	4 Mo	4	F/T	23A
49	SUB-COMM									
50	LONGITUDINAL ACCELERATION	±2G	15508	DONNER 4310	±2G	12-15-70	6 Mo	4	F/T	22B 9
51	ROLL VELOCITY	±40°/sec		US Time	±40°/sec	12-14-70	6 Mo	4	F/T	21B 1
52	LATERAL ACCEL AT PILOT'S HEAD	±0.5G	17103	DONNER 4310	±0.5G	12-18-70	6 Mo	4	F/T	21D 1
53	SUB-COMM									
54	RADAR ALTITUDE	0-5000'				12-10-70	6 Mo	1	F/T	6B 4
55	NORMAL ACCELERATION	-1 to +5G	15503	DONNER 4310	-1 to +3G	12-14-70	6 Mo	4	F/T	22A 9
56	PITCH VELOCITY	±30°/sec	L14342	US TIME	±40°/sec	12-14-70	6 Mo	4	F/T	21A 1
57	SUB-COMM									
58	LATERAL ACCELERATION	±0.5G	15506	DONNER 4310	±0.5G	12-14-70	6 Mo	4	F/T	22C 1
59	LONGITUDINAL ACCELERATION	±0.5G	15505	DONNER 4310	±0.5G	12-15-70	6 Mo	4	F/T	22D 1
60	L/H LOWER FLAP POS	0-42°	150	3" CPT		12-18-70	4 Mo		CPT	26B 12
61	SUB-COMM									
62	PITCH SAS CYLINDER POS (PRI)	±0.5"	161	1" CPT		12-21-70	4 Mo	3	CPT	13A 5
63	PITCH SAS CYLINDER POS (BACK-UP)	±0.5"	164	1" CPT		12-21-70	4 Mo	3	CPT	13B 5
64	ROLL SAS CYLINDER POS (PRI)	±0.5"		1" CPT		12-21-70	4 Mo	3	CPT	13C 5
65	SUB-COMM									
66	ROLL SAS CYLINDER POS (BACK-UP)	±0.5"	147	1" CPT		12-21-70	4 Mo	3	CPT	13D 5
67	YAW SAS CYLINDER POS (PRI)	±0.5"	145	1" CPT		12-21-70	4 Mo	3	CPT	14A 6
68	YAW SAS CYLINDER POS (BACK-UP)	±0.5"	162	1" CPT		12-21-70	4 Mo	3	CPT	14B 6
69	SUB-COMM									
70	R/H LOWER FLAP POS	0-42°	156	3" CPT		12-18-70	4 Mo	3	CPT	26D 12
71	L/H LDG. RKT. CHAM PRESS	0-500	787	PA 822	0-500	12-17-70	4 Mo	2	S/G	15B 5
72	R/H LDG. RKT. CHAM PRESS	0-500	786	PA822	0-500	12-17-70	4 Mo	2	S/G	15C 5
73	SUB-COMM									
74	CONTROL GAS PRESS	0-750	160	PA822	0-750	12-17-70	4 Mo	2	S/G	15D 9
75	GOVERNOR BALANCE PRESS	0-750	157	PA822	0-750	12-17-70	4 Mo	2	S/G	17C 8
76	H_2O_2 TANK PRESS	0-750	159	PA822	0-750	12-17-70	4 Mo	2	S/G	17D 8
77	SUB-COMM									
78	FRAME SYNC 003									
79	FRAME SYNC 145									
80	FRAME SYNC 537									

Table I (Concluded)

DATE 18 FEB 71	Page 2 of 4

				CT-77 S/N	XMTR S/N	P/A S/N	INST ENGR W CLIFTON

CER Calib Date	Period	INST COMPT DISC	SIGNAL CONDITIONING Type	Ch	Conn & Pins IN	OUT	Ra	Rd	Rcal	Sig Level	FILTER 3db Cutoff	db/Oct	Sample Rate	CT-77 Ch	Sub Com & Ch
														41	
12-18-70	4 Mo	3	CPT	25C	9-S,K,P	5-t,w	0	∞	1800/200	HIGH	40 CPS	6	200	42	
12-18-70	4 Mo	3	CPT	25B	9-S,Y,b	5-K,P	0	∞	1800/200	HIGH	40	6	200	43	
12-18-70	4 Mo	3	CPT	25D	9-d,m,r	5-B,E	0	∞	1800/200	HIGH	40	6	200	44	
														45	
10-21-70	4 Mo	3	CPT	26C	12-e,n,s	6-n,s	0	∞	1800/200	HIGH	40	6	200	46	
12-18-70	4 Mo	4	F/T	23B	9-J,M	5-H,L	0	∞	NONE	HIGH	40	6	200	47	
12-18-70	4 Mo	4	F/T	23A	9-H,L	5-A,D	0	∞	NONE	HIGH	40	6	200	48	
														49	
12-15-70	6 Mo	4	F/T	22B	9-W,X	5-R,U	0	∞	NONE	HIGH	40	6	200	50	
12-14-70	6 Mo	4	F/T	21B	10-m,r	5-e,j	0	∞	NONE	HIGH	40	6	200	51	
12-18-70	6 Mo	4	F/T	21D	10-w,t	5-v,x	0	∞	NONE	HIGH	40	6	200	52	
														53	
12-10-70	6 Mo	1	F/T	6B	4-m,r	2-e,j	35K	5000	NONE	HIGH	40	6	200	54	
12-14-70	6 Mo	4	F/T	22A	9-n,s	5-J,M	0	∞	NONE	HIGH	40	6	200	55	
12-14-70	6 Mo	4	F/T	21A	10-K,P	5-Y,b	0	∞	NONE	HIGH	40	6	200	56	
														57	
12-14-70	6 Mo	4	F/T	22C	10-H,A	5-X,Z	0	∞	NONE	HIGH	40	6	200	58	
12-15-70	6 Mo	4	F/T	22D	10-J,B	5-d,h	0	∞	NONE	HIGH	40	6	200	59	
12-18-70	4 Mo		CPT	26B	12-d,m,r	6-e,j	0	∞	1800/200	HIGH	40	6	200	60	
														61	
12-21-70	4 Mo	3	CPT	13A	5-A,H,L	3-A,D	0	∞	1800/200	HIGH	40	6	200	62	
12-21-70	4 Mo	3	CPT	13B	5-B,J,M	3-H,L	0	∞	1800/200	HIGH	40	6	200	63	
12-21-70	4 Mo	3	CPT	13C	5-C,K,N	3-P,T	0	∞	1800/200	HIGH	40	6	200	64	
														65	
12-21-70	4 Mo	3	CPT	13D	5-P,W,Z	3-W,Z	0	∞	1800/200	HIGH	40	6	200	66	
12-21-70	4 Mo	3	CPT	14A	6-C,K,N	3-m,r	0	∞	1800/200	HIGH	40	6	200	67	
12-21-70	4 Mo	3	CPT	14B	6-P,W,Z	3-C,F	0	∞	1800/200	HIGH	40	6	200	68	
														69	
12-18-70	4 Mo	3	CPT	26D	12-t,w,x	6-v,x	0	∞	1800/200	HIGH	40	6	200	70	
12-17-70	4 Mo	2	S/G	15B	5-S,Y,b	5-K,P	5000	3200	50 K	LOW	40	6	200	71	
12-17-70	4 Mo	2	S/G	15C	5-C,K,P	3-t,w	5000	3200	50 K	LOW	40	6	200	72	
														73	
12-17-70	4 Mo	2	S/G	15D	5-d,m,r	3-B,E	5000	3200	50 K	LOW	40	6	200	74	
12-17-70	4 Mo	2	S/G	17C	8-A,H,L	4-X,Z	5000	3200	50 K	LOW	40	6	200	75	
12-17-70	4 Mo	2	S/G	17D	8-B,J,M	4-d,h	5000	3200	50 K	LOW	40	6	200	76	
														77	
													200	78	
													200	79	
													200	80	

Table II

SUBCOMMUTATED INSTRUMENTATION LINE

VEHICLE X-24A | FLT X-23-28 | SUBCOM S/N 511 | CT 77 S

CHAN No	PARAMETER Description	PARAMETER Range	TRANSDUCER S/N	TRANSDUCER Type	TRANSDUCER Range	TRANSDUCER Calib Date	TRANSDUCER Period	INST COMPT DISC	Type	Ch
1	AIRSPEED - COARSE	0-720 PSF	402	WOL		12-2-70	6 Mo	4	CPT	24A
2	AIRSPEED - FINE	72 PSF	402	WOL		12-2-70	6 Mo	4	CPT	24B
3	ALTITUDE - COARSE	0-2100 PSF	403	WOL		12-4-70	6 Mo	4	CPT	24C
4	ALTITUDE - FINE	210 PSF	403	WOL		12-4-70	6 Mo	4	CPT	24D
5	MACH SENSOR	0-26 VAC		WOL		4-10-70	6 Mo	2	F/T	16A
6	MACH SENSOR EXCITATION VOLTAGE	0-26 VAC				1-21-70	6 Mo	2	F/T	16B
7										
8	KRA (INTERCONNECT RATIO)	0-50%	155	2" CPT		12-23-70	4 Mo	4	CPT	20D
9	PITCH TRIM ACTUATOR POS	½"-6⅛"	129	5" CPT		12-21-70	4 Mo	3	CPT	28A
10	ROLL TRIM ACTUATOR POS	±1.75"	152	2" CPT		12-21-70	4 Mo	3	CPT	28B
11	YAW TRIM ACTUATOR POS	±0.8"	153	2" CPT		12-21-70	4 Mo	3	CPT	28C
12	LONGITUDINAL STICK POS	-4⅜"-6⅜"	128	5" CPT		12-21-70	4 Mo	3	CPT	28D
13	LATERAL STICK POS	±6¼"	127	4" CPT		12-21-70	4 Mo	3	CPT	31D
14	RUDDER PEDAL POS	±3"	141	5¾ CPT		12-21-70	4 Mo	3	CPT	32D
15	RADAR ALTITUDE RATE	±60'/sec		RADAR ALTIMETER		7-23-70	4 Mo	1	F/T	16D
16	SAS PITCH GAIN SWITCH POS	1-7	NSN	SWITCH		12-21-70	4 Mo	3	CPT	30A
17	SAS ROLL GAIN SWITCH POS	1-7	NSN	SWITCH		12-21-70	4 Mo	3	CPT	30B
18	SAS YAW GAIN SWITCH POS	1-7	NSN	SWITCH		12-21-70	4 Mo	3	CPT	30C
19	MACH NUMBER	.3-2.5	NSN	MACH REPEATER		12-18-70	6 Mo	4	CPT	30D
20	CHANNEL A YAW GAIN	1-7	NSN	SAS		12-21-70	4 Mo	3	F/T	2A
21	CHANNEL A ROLL GAIN	1-7	NSN	SAS		12-21-70	4 Mo	3	F/T	2D
22	CHANNEL A PITCH GAIN	1-7	NSN	SAS		12-21-70	4 Mo	3	F/T	2C
23	NLG STRUT POSITION	1-11"	158	15" CPT		1-4-71	4 Mo	2	CPT	32A
24	L/H MLG STRUT POSITION	1-12"	157	15" CPT		1-4-71	4 Mo	3	CPT	32B
25	R/H MLG STRUT POSITION	1-12	160	15" CPT		1-4-71	4 Mo	3	CPT	32C
26	L/H FLAP BIAS POS	4°-56°	139	5¾ CPT		10-22-70	4 Mo	3	CPT	14C
27	R/H FLAP BIAS POS	4°-56°	140	5¾ CPT		10-22-70	4 Mo	3	CPT	14D
28	ROLL RATE	±200°/sec		US TIME	±200°/sec	12-14-70	6 Mo		NONE	
29	STRAIN GAGE VOLTAGE	0-12 VDC	NSN	NEFF		1-4-71	4 Mo	-	F/T	23C
30	SAS INVERTER VOLTAGE	0-115 VAC	NSN	SAS INV.		1-21-70	4 Mo	4	F/T	23D
31										
32										
33										
34	No 1 BUS VOLTAGE	0-40 VDC	NSN	#1 BATT		12-23-70	4 Mo		F/T	6A
35	No 2 BUS VOLTAGE	0-40 VDC	NSN	#3 BATT		12-23-70	4 Mo		F/T	6C
36	EQUIPMENT BUS VOLTAGE	0-40 VDC	NSN	EQUIP BATT		12-23-70	4 Mo		F/T	2B
37	ENGINE CHAMBER No 1 PRESSURE	0-500 psi	149	PA 822	0-500	12-15-70	4 Mo	2	S/G	10A
38	ENGINE CHAMBER No 2 PRESSURE	0-500 psi	150	PA 822	0-500	12-17-70	4 Mo	2	S/G	10B
39	ENGINE CHAMBER No 3 PRESSURE	0-500 psi	151	PA 822	0-500	12-17-70	4 Mo	2	S/G	10C
40	ENGINE CHAMBER No 4 PRESSURE	0-500 psi	147	PA 822	0-500	12-17-70	4 Mo	2	S/G	10D

Table II

INSTRUMENTATION LINEUP

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CT 77 S/N	XMTR S/N	P/A S/N	INST ENGR W. CLIFTON

INST COMPT DISC	SIGNAL CONDITIONING								FILTER		Sample Rate	CT 77 Ch	Sub Com & Ch
	Type	Ch	Conn & Pins		Ra	Rd	Rcal	Sig Level	3db Cutoff	db/Oct			
4	CPT	24A	10-C,K,N	5-m,r	R25=	200Ω	1800/200	HIGH	20 CPS	6	50		1
4	CPT	24B	10-P,N,Z	5-C,F	R26=	200Ω	1800/200	HIGH	20	6	50		2
4	CPT	24C	10-R,X,a	5-K,N	R27=	200Ω	1800/200	HIGH	20	6	50		3
4	CPT	24D	10-S,Y,b	5-S,V	R28=	200Ω	1800/200	HIGH	20	6	50		4
2	F/T	16A	8-K,P	4-Y,b	0	∞	NONE	HIGH	20	6	50		5
2	F/T	16B	8-m,r	4-e,j	0	∞	NONE	HIGH	20	6	50		6
								HIGH	20	6	50		7
4	CPT	20D	7-d,m,r	4-R,E	0	∞	1800/200	HIGH	20	6	50		8
3	CPT	28A	11-A,H,L	6-A,D	0	∞	1800/200	HIGH	20	6	50		9
3	CPT	28B	11-B,J,M	6-H,L	0	∞	1800/200	HIGH	20	6	50		10
3	CPT	28C	11-C,K,N	6-P,T	0	∞	1800/200	HIGH	20	6	50		11
3	CPT	28D	11-P,W,Z	6-W,Z	0	∞	1800/200	HIGH	20	6	50		12
3	CPT	31D	14-t,w,x	7-v,x	0	∞	1800/200	HIGH	20	6	50		13
3	CPT	32D	14-B,J,M	7-d,h	0	∞	1800/200	HIGH	20	6	50		14
1	F/T	16D	8-W,Z	4-V,Y	5K IN EACH LEG	∞	NONE	HIGH	20	6	50		15
3	CPT	30A	11-R,X,a	6-c,f	R25=	200Ω	1000/200	HIGH	20	6	50		16
3	CPT	30B	11-S,Y,b	6-K,P	R26=	800Ω	1800/200	HIGH	20	6	50		17
3	CPT	30C	11-c,k,p	6-t,w	R27=	800Ω	1800/200	HIGH	20	6	50		18
4	CPT	30D	11-d,m,r	6-B,E	R28=	220Ω	1800/200	HIGH	20	6	50		19
3	F/T	2A	1-n,s	1-J,M	2000	10K	NONE	HIGH	20	6	50		20
3	F/T	2D	2-J,B	1-d,h	2000	10K	NONE	HIGH	20	6	50		21
3	F/T	2C	2-H,A	1-X,a	2000	10K	NONE	HIGH	20	6	50		22
2	CPT	32A	13-e,n,s	7-J,M	0	∞	1800/200	HIGH	20	6	50		23
3	CPT	32B	13-t,w,x	7-R,U	0	∞	1800/200	HIGH	20	6	50		24
3	CPT	32C	14-A,H,L	7-X,a	0	∞	1800/200	HIGH	20	6	50		25
3	CPT	14C	6-R,X,a	3-K,N	0	∞	1800/200	HIGH	20	6	50		26
3	CPT	14D	6-S,Y,b	3-S,V	0	∞	1800/200	HIGH	20	6	50		27
	NONE	-	DIRECT	-	-	-	NONE	HIGH	20	6	50		28
-	F/T	23C	NONE	5-P,T	14K	10K	NONE	HIGH	20	6	50		29
4	F/T	23D	9-W,P	5-W,Z	0	∞	NONE	HIGH	20	6	50		30
								LOW	20	6	50		31
								LOW	20	6	50		32
								LOW	20	6	50		33
	F/T	6A	4-K,P	2-Y,b	200K	75	NONE	LOW	20	6	50		34
	F/T	6C	4-n,e	2-n,s	200K	75	NONE	LOW	20	6	50		35
	F/T	2B	1-W,X	1-R,U	200K	75	NONE	LOW	20	6	50		36
2	S/G	10A	3-X,U,R,a	2-c,f	5000	3000	100K	LOW	20	6	50		37
2	S/G	10B	3-Y,V,S,b	2-K,P	5000	3200	100K	LOW	20	6	50		38
2	S/G	10C	3-K,f,c,p	2-t,w	5000	3400	100K	LOW	20	6	50		39
2	S/G	10D	3-m,h,d,r	2-B,E	5000	3200	100K	LOW	20	6	50		40

Table II (Concluded)

VEHICLE X-24A | FLT X-23-28 | SUBCOM S/N | CT-77 S/N

CHAN No	PARAMETER Description	PARAMETER Range	TRANSDUCER S/N	TRANSDUCER Type	TRANSDUCER Range	TRANSDUCER Calib Date	TRANSDUCER Period	INST COMPT DISC	Type	Ch
41	BASE PRESS No 7 DIFFER REF	±1.5 PSID	50493	PM131	±1.5	12/8/70	4 Mo	1	S/G	33A
42	L/H UPPER FLAP PRESS # 154	±1.5 PSID	50495	PM131	±1.5	12/8/70	4 Mo	1	S/G	33B
43	L/H UPPER FLAP PRESS # 159	±1.5 PSID	50489	PM131	±1.5	12/8/70	4 Mo	1	S/G	33C
44	L/H UPPER FLAP PRESS # 157 LOWER	±1.5 PSID	50492	PM131	±1.5	12/8/70	4 Mo	1	S/G	33D
45	L/H UPPER FLAP PRESS # 157 UPPER	±1.5 PSID	51005	PM131	±1.5	12/8/70	4 Mo	1	S/G	27A
46	L/H UPPER FLAP PRESS # 156 LOWER	±1.5 PSID	50488	PM131	±1.5	12/8/70	4 Mo	2	S/G	27B
47	L/H UPPER FLAP PRESS # 156 UPPER	±1.5 PSID	50494	PM131	±1.5	12/8/70	4 Mo	2	S/G	27C
48	BASE PRESSURE COMPT REF.	0-15 PSIA	762	PA295	0-25 PSIA	12/8/70	4 Mo	2	S/G	27D
49	No 1 HYDRAULIC SYSTEM PRESSURE	0-3000 psi	1088	PA324	0-5000	12-17-70	4 Mo	4	S/G	8A
50	No 2 HYDRAULIC SYSTEM PRESSURE	0-3000 psi	1099	PA324	0-5000	12-17-70	4 Mo	2	S/G	8B
51	LOX TANK PRESSURE	0-100 psi	96	PA822	0-150	12-17-70	4 Mo	2	S/G	18A
52	LOX MANIFOLD PRESSURE	0-500 psi	156	PA822	0-500	12-17-70	4 Mo	2	S/G	18B
53	ALCOHOL TANK PRESSURE	0-100 psi	100	PA822	0-150	12-17-70	4 Mo	2	S/G	18C
54	ALCOHOL MANIFOLD PRESSURE	0-500 psi	148	PA822	0-500	12-17-70	4 Mo	2	S/G	18D
55	No 1 HELIUM SOURCE PRESSURE	0-5000 psi	1086	PA324	0-5000	12-17-70	4 Mo	2	S/G	17A
56	No 2 HELIUM SOURCE PRESSURE	0-5000 psi	4385	PA324	0-5000	12-17-70	4 Mo	2	S/G	17B
57	PITCH ANGLE	±90°	—	ATTITUDE SYSTEM		12-17-70	6 Mo	4	CPT	31A
58	ROLL ANGLE	±90°				12-17-70	6 Mo	4	CPT	31B
59	YAW ANGLE	±180°				12-17-70	6 Mo	4	CPT	31C
60	TS-108	-70 to +150	NSN	STG-50		12-22-70	6 Mo	2	CPT	12B
61	TS-106	-70 to +150°	NSN	STG-50		12-22-70	6 Mo	2	CPT	12C
62	TS-107	-70 to +150 F	NSN	STG-50		12-22-70	6 Mo	2	CPT	12D
63										
64	ENGINE NOZZLE EXTENSION TEMP	400 to 2000	NSN	CR-AL T/C		9-24-70	6 Mo	7	F/T	7D
65	H2O2 TANK TEMP	0-150 F	NSN	ROSEMOUNT		12-22-70	6 Mo	3	CPT	7OC
66										
67	HYD PUMP MOTOR TEMP @ NAMEPLATE	0-400 F	NSN	STG-50		12-23-70	6 Mo	5	CPT	9A
68	ENGINE CONTROL BOX TEMP	140 to -50	NSN	STG-50		12-23-70	6 Mo	5	CPT	9B
69	LOX PRIME LINE TEMP	-320 to -200	NSN	STG-50		12-23-70	6 Mo	5	CPT	9C
70	INSTRU. COMPT TEMP	-60 to +250	NSN	MINCO		12-23-70	6 Mo	—	CPT	9D
71	FRAME SYNC (715)	—	—	—	—	—	—	—	—	—
72	No 1 BUS CURRENT	0-250A	NSN	CURRENT SENSOR	0-250A	12-23-70	6 Mo	2	F/T	19A
73	No 2 BUS CURRENT	0-250A	NSN	CURRENT SENSOR	0-250A	12-23-70	6 Mo	2	F/T	19B
74	EQUIPMENT BUS CURRENT	0-200A	NSN	CURRENT SENSOR	0-250A	12-22-70	6 Mo	2	F/T	19C
75	INSTRU/EMERG BUS CURRENT	0-150A	NSN	CURRENT SENSOR	0-250A	12-23-70	6 Mo	2	F/T	19D
76	TS-101	-70 to +150	NSN	STG-50		12-22-70	6 Mo	1	CPT	11A
77	TS-102	-70 to +150	NSN	STG-50		12-22-70	6 Mo	1	CPT	11B
78	TS-103	-70 to +150	NSN	STG-50		12-22-70	6 Mo	5	CPT	11C
79	TS-104	-70 to +150	NSN	STG-50		12-22-70	6 Mo	5	CPT	11D
80	TS-105	-70 to +150	NSN	STG-50		12-22-70	6 Mo	5	CPT	12A

Table II (Concluded)

DATE 18 FEB 71 | Page 4 of 4

CT-77 S/N | XMTR S/N | P/A S/N | INST ENGR W. CLIFTON

…ge	Calib Date	Period	INST COMPT DISC	Type	Ch	Conn & Pins IN	Conn & Pins OUT	Ra	Rd	Rcal	Sig Level	3db Cutoff	db/Oct	Sample Rate	CT 77 Ch	Sub Com & Ch
	12/8/70	4 Mo	1	S/G	33A	13 H,D,A,L	7-A,D	1300	5000	100K	Low	20 CPS	6	50		41
	12/8/70	4 Mo	1	S/G	33B	13 J,E,B,M	7-H,L	1200	5000	100K	Low	20	6	50		42
	12/8/70	4 Mo	1	S/G	33C	13 K,F,C,N	7-P,T	0	∞	100K	Low	20	6	50		43
	12/8/70	4 Mo	1	S/G	33D	13 W,T,P,Z	7-W,Z	1000	5000	100K	Low	20	6	50		44
	12/8/70	4 Mo	1	S/G	27A	11 u,v,e,s	6 J,M	C	∞	100K	Low	20	6	50		45
	12/8/70	4 Mo	2	S/G	27B	11 w,v,t,x	6 R,U	620	5000	100K	Low	20	6	50		46
	12/8/70	4 Mo	2	S/G	27C	12 H,D,A,L	6-X,a	360	5000	100K	Low	20	6	50		47
	12/8/70	4 Mo	2	S/G	27D	12 J,E,B,M	6-d,h	1200	10K	100K	Low	20	6	50		48
	12-17-70	4 Mo	4	S/G	8A	3-H,D,A,L	2-A,D	750	5000	100K	Low	20	6	50		49
	12-17-70	4 Mo	2	S/G	8B	3-J,E,B,M	2 H,L	910	5000	100K	Low	20	6	50		50
	12-17-70	4 Mo	2	S/G	18A	7-H,D,A,L	4-A,D	0	∞	100K	Low	20	6	50		51
	12-17-70	4 Mo	2	S/G	18B	7 J,E,B,M	4-H,L	5000	3200	50K	Low	20	6	50		52
	12-17-70	4 Mo	2	S/G	18C	7-K,F,C,N	4-P,T	5000	10K	100K	Low	20	6	50		53
	12-17-70	4 Mo	2	S/G	18D	7-W,T,P,Z	4-W,Z	5000	2800	50K	Low	20	6	50		54
	12-17-70	4 Mo	2	S/G	17A	7-n,j,e,s	4-J,M	5000	5000	50K	Low	20	6	50		55
	12-17-70	4 Mo	2	S/G	17B	7-w,v,t,x	4-R,U	5000	5000	50K	Low	20	6	50		56
	12-17-70	6 Mo	4	CPT	31A	14-c,k,p	7-Y,b	250K	1200	1820/200	Low	20	6	50		57
	12-17-70	6 Mo	4	CPT	31B	14-d,m,r	7-e,j	250K	1200	1820/200	Low	20	6	50		58
	12-17-70	6 Mo	4	CPT	31C	14-e,n,s	7-n,s	500K	1200	1820/200	Low	20	6	50		59
	12-22-70	6 Mo	2	CPT	12B	5-t,w,x	3-R,U	R_{26} =	2490	1050/1020	Low	20	6	50		60
	12-22-70	6 Mo	2	CPT	12C	6-A,H,L	3-X,a	R_{27} =	6490	1060/1020	Low	20	6	50		61
	12-22-70	6 Mo	2	CPT	12D	6-B,J,M	3-d,h	R_{29} =	6490	1060/1020	Low	20	6	50		62
											Low	20	6	50		63
	9-24-70	6 Mo	7	F/T	7D	4-J,B	2-d,h	1500	5000	NONE	Low	20	6	50		64
	12-22-70	6 Mo	3	CPT	20C	7-c,k,p	4-t,w	R_{27} =	24.9K	1050/1020	Low	20	6	50		65
											Low	20	6	50		66
	12-23-70	6 Mo	5	CPT	9A	4-C,K,N	2 m,r	R_{25} =	13K	1050/1020	Low	20	6	50		67
	12-23-70	6 Mo	5	CPT	9B	4-P,W,Z	2-C,F	R_{26} =	1780	1050/1020	Low	20	6	50		68
	12-23-70	6 Mo	5	CPT	9C	4-R,X,a	2-K,N	R_{27} =	1580	1050/1050	Low	20	6	50		69
	12-23-70	6 Mo	—	CPT	9D	4-S,Y,b	2-S,V	R_{28} =	29.4K	1050/1020	Low	20	6	50		70
	—	—	—	—	—	—	—	—	—	—	—	—	—	50		71
0A	12-23-70	6 Mo	2	F/T	19A	8-K,N	4-m,r	45K	5000	NONE	Low	20	6	50		72
A	12-23-70	6 Mo	2	F/T	19B	8-W,Z	4-C,F	45K	5000	NONE	Low	20	6	50		73
0A	12-22-70	6 Mo	2	F/T	19C	8-X,R	4-K,N	35K	5000	NONE	Low	20	6	50		74
0A	12-23-70	6 Mo	2	F/T	19D	8-Y,S	4-S,V	25K	5000	NONE	Low	20	6	50		75
	12-22-70	6 Mo	1	CPT	11A	6-c,k,p	3-Y,b	R_{25} =	6490	1050/1020	Low	20	6	50		76
	12-22-70	6 Mo	1	CPT	11B	6-d,n,r	3-e,j	R_{26} =	6490	1050/1020	Low	20	6	50		77
	12-22-70	6 Mo	5	CPT	11C	6-e,n,s	3-n,s	R_{27} =	6490	1050/1020	Low	20	6	50		78
	12-22-70	6 Mo	5	CPT	11D	6-t,w,x	3-v,x	R_{28} =	6490	1050/1020	Low	20	6	50		79
	12-22-70	6 Mo	5	CPT	12A	5-e,n,s	3-J,M	R_{25}	6490	1050/1020	Low	20	6	50		80

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FLIGHT PLANNING AND CONDUCT OF THE X-24A LIFTING BODY FLIGHT TEST PROGRAM

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Aerospace Engineer

TECHNOLOGY DOCUMENT No. 71-10

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